REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
26.Oct.98

3. REPORT TYPE AND DATES COVERED
MAJOR REPORT

4. TITLE AND SUBTITLE
PRESSURE FED LAUNCH ELEMENT FOR THE SPACE TRANSPORTATION SYSTEM (STS)

5. FUNDING NUMBERS

6. AUTHOR(S)
2D LT GINN JASON R

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UNIVERSITY OF COLORADO AT COLORADO SPRINGS

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CIA, BLDG 125
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
98-011

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited distribution
In Accordance With AFI 35-205/AFIT Sup 1

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

19981119 018

DTIC QUALITY INSPECTED 4

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

Pressure Fed Launch Element

For the

Space Transportation System (STS)

Jason R. Ginn
Master's Creative Investigation
Master's of Aerospace Engineering
Spring 1998

Abstract

The turbo-pump machinery used to feed propellant from the external tank of the Space Transportation System into the Space Shuttle Main Engines is a costly and complex system. One method by which to reduce this cost and complexity is to develop a pressure fed propellant system. This paper investigates the feasibility of utilizing a pressurant system as a means to feed propellant to the Space Shuttle Main Engines. This investigation addresses a situation as simple as replacing the turbo pumps with a pressurant tank to more complex situations of staging the Shuttle launch system to reduce needed propellant. The results of this investigation are not as optimistic as first anticipated. From the top-level analysis, a pressure fed system is highly unfeasible as well as impossible. This is a result of the current tank technology as well as the physics of the situation.

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1.0 Introduction

The Space Transportation System (STS), or Space Shuttle, is both a complex and costly device for inserting payloads into space. The propellant feed system for the Space Shuttle Main Engines (SSME's) is no exception. To provide the necessary thrust and specific impulse for lift-off and orbit insertion, the SSME's utilize turbo pumps to furnish the essential pressures and mass flow rates of the oxidizer and fuel. This method of feeding propellants to liquid rocket engines is both complex and costly. Turbo pumps contain many high speed moving parts at high temperatures. The complexity of moving parts compounded by high speeds and high temperatures adds to the risk of failure as well as to the cost of high maintenance.

To remedy this cost and complexity, a pressure fed system is being proposed to replace the current pump system. A pressure fed system consist mainly of pressure valves and propellant and pressurant tanks. These objects are passive in nature and as a result, contain little or no moving parts. This reduces the overall complexity, cost, and risk of the STS mission. In attempt to minimize new design and testing which will restrain the costs, the proposed system utilizes as much of the current system as possible. In addition, the investigation will look at the capability of launch system reusability, including any large external propellant tank.

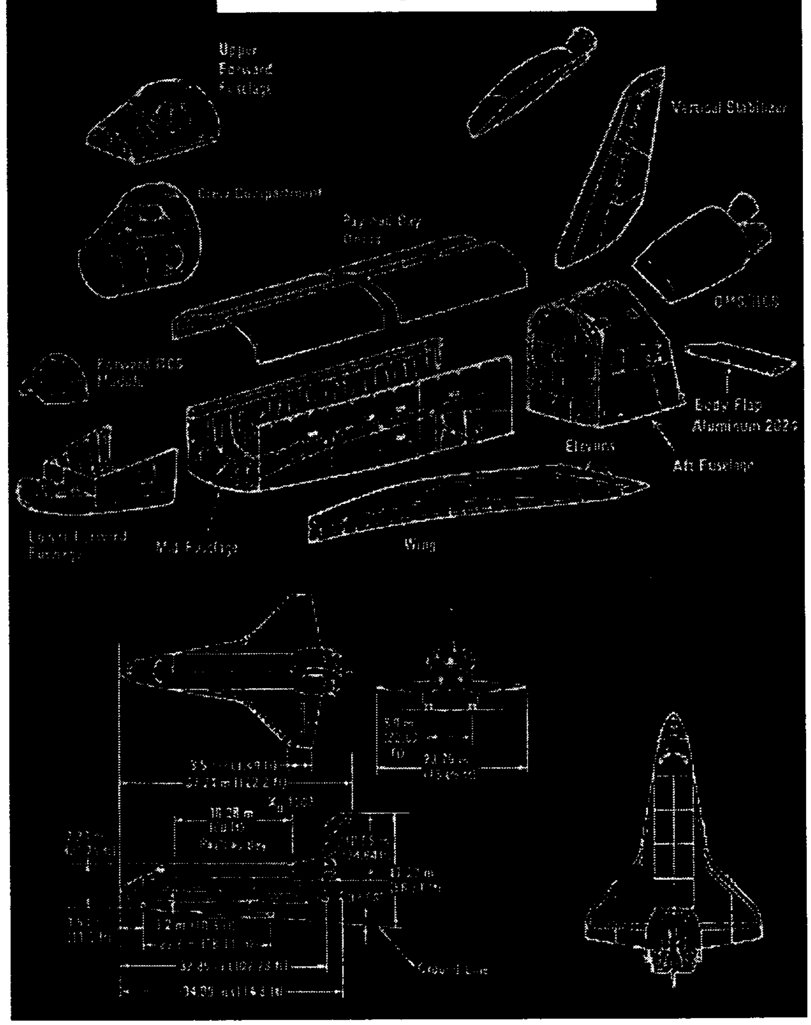
2.0 Background

2.1 Space Transportation System

Before altering and modifying the Space Transportation System, a better understanding of the current system is essential. The following section addresses the basic vocabulary, elements, and subsystems of the current system.

The Space Transportation System (STS) consists of three main segments, the orbiter, external tank (ET), and solid rocket motors/boosters (SRM/SRB). Each system works together in parallel fashion to allow the launch system to achieve orbit insertion.

Figure 2.2



2.1.a Orbiter

The orbiter (Figure 2.2, Table 2.2) is the principal element of the STS and is designed to last approximately 100 flights [1]. This winged vehicle is both an aircraft and a spacecraft; acting as a spacecraft during launch and on-orbit operations, and as a

aircraft while performing an unpowered descent back to Earth. While the exact values for orbiter dimensions and payload capabilities vary between each orbiter (i.e. Enterprise, Columbia, Atlantis, etc.) the following are approximate values obtained from the Space Shuttle Operator's Manual [1] and can be viewed in Table 2.2.

ORBITER (Table 2.2)	
$m_{orb\ tot}$ (empty) (kg)	75,000.00
$m_{orb\text{-}P/L}$ (kg)	29,500.00
$m_{orb\ w/P/L}$ (kg)	104,500.00
wingspan (m)	24.00
height (m)	17.25
length (m)	37.24

The orbiter has the capability of carrying a 4.5-by-18-meter payload with a mass up to 29,500 kg (Table 2.2) into an approximate 300km, 28.5-57 degree inclination orbit. It has a wingspan of 24 meters, a height—including landing gear—of 17.25 meters, and length of 37.24 meters.

2.1.b SSME

This vehicle also houses one of the main elements of concern throughout this paper, the three Space Shuttle Main Engines (SSME's). This element of the orbiter is one of the most crucial to this paper. Values and terms mentioned below are referred to throughout this paper, specifically in sections 3-5. The values of greatest interest are the chamber pressure, thrust, and specific impulse.

Figure 2.3

The SSME's (Figure 2.3, Table 2.3) are the most advanced liquid fueled engines ever developed and are currently a product of the Rocketdyne division of Boeing. The SSME's have a 100% flight success rate with a demonstrated reliability of over .999 [3]. The SSME is a reusable staged-combustion cycle engine, using a 6-to-1 liquid oxygen (LOX) and liquid

hydrogen (LH) mixture to fuel the engine. Its main features include variable thrust and regenerate cooled nozzle and combustion chamber (fuel runs through tubes in the nozzle and combustion chamber wall to transfer heat from the nozzle and chamber to the fuel), and vector thrusting (gimballed engine). The engine has the capability of producing 2,174,286 Newtons (488,000 lbs) of thrust at a 104% power rating, 1,734,803 Newtons (390,000 lbs) at sea level [4]. It also has a maximum thrust capability of 2,278,824 Newtons (512,300 lbs) at a 109% power rating for emergency purposes. The SSME's operate with an chamber pressure of 22,614,804 Pa (3280 psia), which is the major driving factor for this project, and a total mass flow rate of 487.12 kg/s. In addition, the SSME contains a bell shaped nozzle with an expansion ratio (ε) of 77.5:1 and exit diameter of 2.44 m. Currently, the engines feature high performance turbo pumps to boost the propellant pressure and mass flow rate which is covered in section 2. Of greatest concern is the required chamber pressure and mass flow rate necessary for the engines to produce the aforementioned thrust and specific impulse of 454.5 seconds.

SSME (Table 2.3)	
m_{SSME} (overall) (kg)	3,174.00
$thrust_{SSME}$ (104%) (N)	2,174,286.00
# of engines	3.00
$m_{SSME\ tot}$ (kg)	9,522.00
$thrust_{SSME\text{-}tot}$ (104%) (N)	6,522,858.00
$m_{LH\text{-}pump}$ (kg)	34.00
$m_{OX\text{-}pump}$ (kg)	11.30
$m_{thrust\text{-}vect}$ (kg)	669
Isp_{SSME} (s)	455.00
mixture ratio (O/F)	6:1
length (m)	4.27
diameter (m)	2.44

$$Isp = \frac{F}{\dot{m} g_o}; g_o = 9.81 \frac{m}{s^2}$$

$$F = thrust \qquad ; \text{ (equation 2.1)}$$

$$\dot{m} = mass \quad flow \quad rate$$

Specific impulse, equation 2.1, is a common performance parameter which compares the thrust derived from a system as a function of the propellant mass flow rate [5]. Because of turbo pump limitations with mass flow rates and pressure rise, the thrust, based off of equation 2.1, of the SSME is greatly limited to the aforementioned maximum value of 2,278,824 Newtons. As a result of this low thrust, the 3 SSMEs cannot provide a sufficient initial thrust-to-weight ratio (F/W) for shuttle lift-off. As a consequence, the two solid rocket motors, which is the next element of discussion, are added to the system to greatly increase the initial F/W to approximately 1.5.

1.1.c Solid Rocket Motor (SRM)

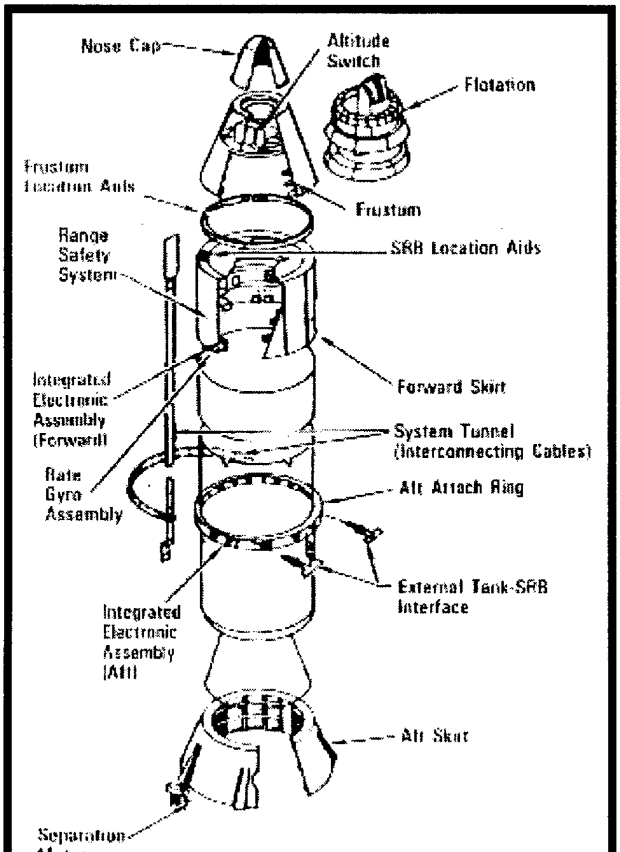


Figure 2.4

The Solid Rocket Motors, SRM's (Figure 2.4, Table 2.4), are the largest solid propellant rocket motors ever flown and the first designed for reuse [6]. Each booster is approximately 45.5 meters in length and 3.7 meters in diameter. At initial launch, one booster is approximately 585,841 kg, with 87,060kg being inert mass and 498,781 kg being solid propellant. Each booster has primary elements consisting of the motor, structure, separation systems, operational

flight instrumentation, recovery avionics, pyrotechnics, deceleration system, thrust vector control system and range safety destruct system [6]. Of greatest concern for this investigation is the motor and structure elements, and as a result the details of the SRM's construction and design are ignored. These two elements are primary driving factors in section 3. In addition, since the SRM's themselves will not be altered in any fashion, with the exception of attachment to the external tank, only the relevant information (i.e. thrust, mass, etc.) is addressed in this section.

The main characteristics (table 2.4) of concern for the structure and motor elements are the thrust, mass, specific impulse, burn time, and structural purposes. Each booster has the capability of 11.8 million Newtons of thrust and 242 seconds of Isp (268.6s in vacuum) at initial lift-off. Special note, however, is made 50 seconds after lift-off; at this point in the ascent phase, the thrust is reduced by almost 1/3 the initial value to prevent overstressing the vehicle during maximum dynamic pressure [6]. This reduction of thrust is of significant when developing the designs in section 3. As previously mentioned, the motor houses 498,781 kg of a propellant mixture consisting of ammonium perchlorate (oxidizer), aluminum (fuel), iron oxide (catalyst), a polymer (a binder holding the mixture together), and an epoxy curing agent. The structure has a mass of 87,060 kg and serves several purposes besides housing the propellant, one of which is carrying the entire weight of the external tank and orbiter and transmitting the weight load to the mobile launcher platform. This fact is of vital interest in any of the designs where the SRM's are eliminated. In addition to the above characteristics, the burn time is very important to the later

SRM (Table 2.4)	
$m_{SRM\text{-}inert}$ (kg)	87,060.00
$m_{SRM\text{-}prop}$ (kg)	498,781.00
$m_{drogue\text{-}chute}$ (kg)	5,338.00
$thrust_{boosters}$ (N)	11,800,000.00
# of motors	2.00
$m_{booster\ tot\ inert}$ (kg)	174,120.00
$m_{booster\ tot\ wet}$ (kg)	1,171,682.00
$thrust_{booster\text{-}tot}$ (N)	23,600,000.00
$Ips_{booster\text{-}SL}$ (s)	242.00
$Ips_{booster\text{-}vac}$ (s)	268.60
length (m)	45.5
diameter (m)	3.7

investigative design sections. The length of time that the boosters burn greatly affects any staging that occurs in these later sections. On the current STS missions, the SRM's burn for approximately the first 2 minutes of ascent, at which time they separate from the external tank at their two attachment points on the aft frame and forward end of the boosters.

The solid rocket boosters provide a significant amount of thrust making them a necessary evil. The SSME's alone cannot lift the shuttle off the ground, and as a result the 2 boosters are required. The boosters' short-comings occur in the low Isp and controllability. From equation 2.1, the low 242s Isp affects the over-all 269s Isp of the first stage (SRM & SSME parallel combination) by reducing the high 454s Isp of the SSME's. In addition, the SRM's utilize solid propellant. The major characteristics of solid propellants are that they are not restartable, and once they are ignited they burn until the propellant is gone.

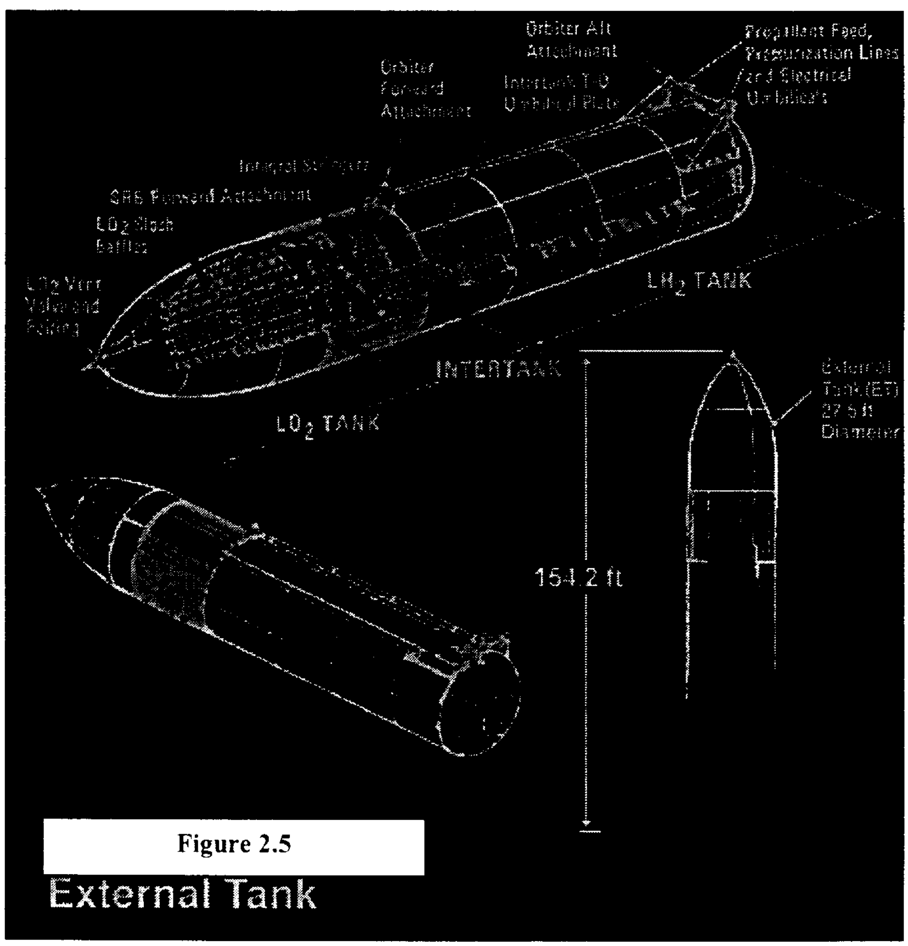


Figure 2.5

1.1.d External Tank

Equally as important as the previous elements, but essential to Space Shuttle Main Engine operation is the external tank, ET (Figure 2.5,

Table 2.5). The ET is the largest and heaviest element of the space shuttle, costing approximately 30 million dollars, and being the only disposable structure of the Space Transportation System. It consists of three major components: the forward liquid oxygen tank, the mid intertank housing the main electrical components, and the aft liquid hydrogen tank [7]. Of immense concern to this paper are the dimensions and volume, and the amount of propellant contained within the ET. In addition, the means by which the propellant is transported into the orbiter and thus the engines requires equal consideration.

The liquid oxygen tank is located in the top or front section of the ET and is constructed as an aluminum monocoque structure. It operates at a pressure range of 137,895-151,684 Pa (20-22 psig). The oxygen tank feeds into a 43cm feed-line, which runs through the intertank, then outside the ET to the aft right-hand ET/orbiter disconnect umbilical [7]. The tank itself has a volume of 558.26 m3 (19,714.77 ft3), a diameter of 8.41m (331 in), a height of 15.03m (592 in), and dry mass of 5,441kg (12,000 lbs).

External Tank (Table 2.5)	
$m_{ET\text{-}tot}$ (dry) (kg)	35,500.00
$m_{ET\text{-}tot}$ (wet) (kg)	754,000.00
LH Tank	
$m_{LH\text{-}tank}$ (dry) (kg)	13,150.00
m_{LH} (kg)	102,000.00
p_{LH} (Pa)	220,632-234,421
vol_{LH} (m^3)	1,512.23
diameter (m)	8.41
length (m)	29.46
OX Tank	
$m_{OX\text{-}tank}$ (dry) (kg)	5,441.00
m_{OX} (kg)	616,500.00
p_{ox} (Pa)	137,895-151,684
vol_{OX} (m^3)	558.26
diameter (m)	8.41
length (m)	15.03
Misc	
$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00

The Intertank is a steel/aluminum semimonocoque cylindrical structure. Its purpose is to join the oxygen and hydrogen tanks, as well as house many of the components necessary for proper operation of the ET. It is 8.41m (331 in) in diameter, 6.85m (270 in) long, and weighs 5,487kg (12,100 lbs).

The liquid hydrogen tank is an aluminum semimonoque structure operating at 220,632-234,421 Pa (32-34 psia). Like the oxygen tank, it has a 43cm (17 in) diameter feed-line which connects to the left-aft umbilical. At the forward end of the hydrogen tank is the ET/orbiter forward attachment pod strut, and at its aft end are the two ET/orbiter aft attachment ball fittings as well as the aft SRB-ET stabilizing strut attachments [7]. The liquid hydrogen tank is 8.41m (17 in) in diameter, 29.46m (1,160 in) long, 1,512.23m3 (53,518 ft3) in volume, and has a dry weight of 13,150kg (29,000 lbs).

In addition to the main tank components, other masses are accounted for in this investigation. These components consist of the thermal protection and external hardware. Though the actual masses may vary with a modified system, this is only a top-level analysis and therefore the values presented in Table 2.5 will be the ones used in the following sections.

2.2 Turbo Pumps

The turbo pumps (Figure 2.6, Table 2.6) are the instrument by which the rocket propellants are fed from the External Tank into the Space Shuttle Main Engines. This system consists of a low pressure oxidizer turbo pump (LPOT), high pressure oxidizer turbo pump (HPOT), low pressure fuel turbo pump (LPFT), and high pressure fuel pump (HPFT), for each engine. The bulk of this information is obtained from the Space Shuttle Main Engines section of the Space

Turbo Pumps (Table 2.6)

	Oxidizer Pump	Fuel Pump
Low pressure		
p_{inlet} (Pa)	689,475	206,843
p_{exit} (Pa)	2,909,587	1,902,953
speed (rpm)	5,150	16,185.00
Dimensions (cm)	45.72 X 45.72	45.72 X 60.96
High pressure		
p_{inlet} (Pa)	2,909,587	1,902,953
p_{exit} (Pa)	51,159,099	44,919,343
speed (rpm)	23,600	36,200
Shaft Horsepower (hp)	27,350	73,000
Service Life (missions)	60	60
Design Life (missions)	240	240
Dimensions (cm)	61 X 91	56 X 112

Shuttle Reference Manual [8]. Below is only a brief summary of the turbo pump operation. This operation is very complex and tedious, refer to the aforementioned web-site for details on the turbo pumps.

2.2.a Oxidizer Turbo Pumps

The oxidizer is fed into the main propulsion system liquid oxygen feed line from the aforementioned orbiter/ET umbilical disconnect. From this point it branches out into three parallel paths leading to the LPOT of each engine. "The LPOT is an axial-flow pump driven by a six-stage turbine powered by liquid oxygen" [8]. The LPOT boosts the liquid oxygen pressure from 689,445 Pa (100psia) to an exit pressure of 2,909,587 Pa (422 psia). From the exit of the LPOT, the liquid oxygen is fed into the HPOT. The LPOT allows the HPOT to operate at high speeds without cavitation. The LPOT operates at about 5,150 rpm, and has dimensions approximating 45.72 cm (18 in) by 45.72 cm. The LPOT's attached to the orbiters structure in a fixed position.

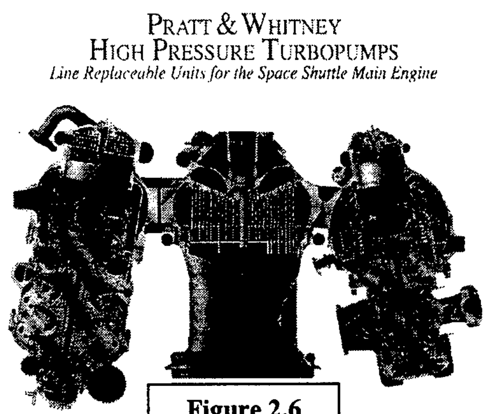


Figure 2.6

"The HPOT consists of two single-stage centrifugal pumps mounted on a common shaft and driven by a two stage, hot-gas turbine" [8]. The main pump operates at 28,120 rpm and boosts the oxygen from the exit pressure of the LPOT (2,909,587 Pa, 422 psia), to 29,647,456.4 Pa (4,300psia). The liquid oxygen path then splits into several directions. One goes to fuel the LPOT turbine, one travels to the main combustion chamber, and another taps off to the oxidizer heat exchanger which is used to convert some of the oxygen into gas. This gas is used to pressurize the oxidizer

tank and also enters the HPOT second-stage preburner pump to boost the liquid oxygen to 51,159,099 Pa (7,420 psia). This gas also passes through the HPFT preburner pump. The HPOT is approximately 60.96 cm (24 in) by 91.44 cm (36 in).

2.2.b Fuel Pump

Like the liquid oxygen, the liquid hydrogen enters the orbiter and splits off into three parallel paths, which lead to the LPFT. "The LPFT is an axial-flow pump driven by a two-stage turbine powered by gaseous hydrogen" [8]. The LPFT boosts the liquid hydrogen from 206,842.7 Pa (30 psia) to 1,902,953.01 Pa (276 psia) which then feeds into the HPFT. Like the LPOT, the LPFT allows the HPFT to operate at high speeds without cavitation. The LPFT is 45.72 cm (18 in) by 60.96 cm (24 in) and operates at approximately 16,185 rpm. It too is attached to the orbiter structure at 180 degrees from the LPOT.

"The HPFT is a three-stage centrifugal pump driven by a two-stage, hot gas turbine" [8]. It is used to boost the liquid hydrogen pressure to 44,919,343.77 Pa (6,515 psia) while operating at 35,360 rpm. The outlet is then branched off into three separate paths. One path cools the combustion chamber and then feeds to run the LPFT turbine. The remaining hydrogen passes between the inner an outer wall to cool the hot-gas manifold, which is then discharged into the main combustion chamber. The second path is sent through the engine nozzle to cool it. It then joins the third flow path from the chamber coolant. This combined flow is then directed to operate the fuel and oxidizer preburners. The HPFT is 55.88 cm (22 in) by 111.76 cm (44 in).

3.0 Investigation of Pressure-fed System

3.1 Current System with Pressurant Tank

The most simplistic and cost effective approach is to simply remove the turbo pumps and replace them with a pressurant tank. This idea requires minimal change in the existing system. With this notion, the SSME's, and SRM's are not altered. In addition, the launch profile and sequence is not modified.

The basic idea is to have the turbo pumps removed from the orbiter. Then a pressurant tank and pressurant are added to the ET. Through the use of the pressurant, the oxidizer and fuel are pushed through the plumbing from the ET into the engines on the orbiter. Because of the simplicity of the idea and lack of modification in the existing system, the new system will require little design and testing. In addition, the only thing being altered is the propellant feed method, therefore the engines and boosters remain the same. As a result, the over all launch portion of the mission profile does not change. However, with the addition of the pressurant tank, the external tank's geometry and size is altered.

In the following sub-sections the investigation of this idea is explained in detailed. A conclusion is made on the feasability of this notion. The process for obtaining this conclusion is described, along with the equations used and the resultant values.

3.1.a Pressurant Mass and Volume Determination

To begin, the values of the current system's liquid propellant masses and flow characteristics are obtained from Tables 2.2-2.6. The values that are of greatest concern are the liquid oxygen and

liquid hydrogen masses, volume, and flow rates. With this information, the pressurant mass and volume are determined using Algorithm 3.1. The following algorithm is from the class notes for ASE 521 at the University of Colorado at Colorado Spring by Captain Michael Bettner [4].

Algorithm 3.1: Pressurant (Vol_{OX}, Vol_{LH}, $p_{initial}$, p_{final}, $T_{initial}$ $\Rightarrow$ Vol_{press}, m_{press})

1. Assume pressurant tank volume ($Vol_{press\ tank}$) = 0
2. Estimate volume of pressurant (Vol_{press})
   - Start with enough to fill all tanks +5% extra
   - $Vol_{press} = (Vol_{OX}+Vol_{LH}+Vol_{press\ tank}) * 1.05$ (equation 3.1)
3. Select initial temp ($T_{initial}$), initial pressure ($p_{initial}$), and final pressure (p_{final}) for the pressurant; the final pressure is equal to the HPOT outlet pressure plus a small margin for dynamic pressure drop and losses due to plumbing. The temperatures must be above the critical temperature to guarantee that the propellant remains a liquid.

$$T_{final} = T_{initial}\left(\frac{p_{final}}{p_{initial}}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{(equation 3.2)}$$

4. Use isentropic relationship to find the final temperature (T_{final})

$$m_{press} = \frac{p_{final}Vol_{press}}{RT_{final}} \quad \text{(equation 3.3)}$$

5. Use ideal gas law to determine the mass of the pressurant
6. Use equation 3.3 at $T_{initial}$ and $P_{initial}$ to find $Vol_{press\ tank}$ to hold mass of pressurant
7. Go back to step two with $Vol_{press\ tank}$ until it converges

---

3.1.b Tank Sizing

Tank mass sizing can be performed by two methods. The first approach is called Hoop Stress. This method utilizes material strength, and burst pressure (MEOP, burst pressure, times a factor of safety). The second approach is an empirical method using pressure, volume, and a tank factor (φ_{tank}). This tank factor is usually supplied by the manufacturer and is determined by the tank material. Table 3.1 lists some tank factors for some of the common propellant tank materials. For this investigation and all those to follow, the tank sizing is determined using method 2, the tank factor approach. For this approach, the following equation is used to determine the tank masses:

Common Tank Factors (m) (Table 3.1)	
metallic	2,500
graphite composite	10,000
graphite composite -T1000G [9]	50,000

$$m_{tank} = \frac{p_b Vol_{tot}}{g_o \varphi_{tank}} \qquad \text{(equation 3.4)}$$

In this equation, the pressure is the burst pressure (pressure of system plus a safety factor) for the tanks. However, an exception is made for tanks made of titanium; the tank factor for titanium already includes a factor of safety equal to 2. In this section as well as in the following sections, tanks consisting of either titanium or composites are considered. These materials are chosen for their high tank factors, as seen in Table 3.1. One might ask why the material with the highest tank factor is not always used. The reasons are many (cost is a large factor), but for this situation one of the limiting factors is the propellants. The propellants for this situation are cryogenic (operating at very low temperatures); this can hinder the use of some composites. As

of 1995, “the use of composite tank materials has not been demonstrated for cryogenic propellants because of concern for brittleness” [5]. Because of this aforementioned situation, composite materials are used only for the pressurant tank.

As for the geometry of the tanks, they are modeled as spheres. This is initially done for this investigation, as well as the following investigations for simplicity sake. Once a method is found that works within the mass limitations, the tanks will be modeled as cylinders, which is more complicated but is more common for tanks of this size.

3.1.c Optimizing Pressurant Mass

Now that the process for determining pressurant mass and volume and tank size and mass has been addressed, the method by which an optimal solution is achieved can be presented. To begin, the situation presented in this section has both fixed propellant volume and mass. As a result, the volume of the propellant tanks is predetermined. On the contrary, the mass and the volume of the pressurant can be altered through variation in initial pressurant tank pressure ($p_{initial}$) as an increase in final pressure. In order to find the optimal solution, varying $p_{initials}$ are implemented in conjunction with Algorithm 3.1 and Equation 3.4. These calculations for various pressurants and tank materials are displayed in Tables B.1-B.6 and Charts B.1-B.6 in Appendix B. The reason for testing several pressurants over a range of increasing initial pressures is simple. First, by increasing the initial pressure of the pressurant one can reduce the volume and hence, the mass of the pressurant. From Equation 3.4, reducing the volume of the pressurant reduces the pressurant tank size, which in-turn decreases the mass of the tank. However, the increase in pressure will require a thicker tank wall—increasing the tank mass (see

equation 3.4). This problem is not great, for the reduction in volume due to increase in pressure out-weighs the increase in wall-thickness.

The reasoning behind testing different pressurants is simple as well. Because of the various specific heat ratios (γ) and molecular weights (M), some elements are more optimal than others in the current situation. Among the most commonly used pressurants include Helium (He), Argon (Ar), and Nitrogen (N_2), and are the three different pressurants investigated in each section. Note should be made that a pressurant needs to be inert; a pressurant cannot react with the propellants or the storage tanks.

3.1.d Results

As previously mentioned, several combinations of tank materials and pressurants are tested. The best results (Table 3.2) occur for propellant tanks made of titanium with helium as the pressurant. As for the pressurant tanks, a composite material works best, and two types are used. One has a tank factor of 10,000 meters (denoted situation 1) and the other has a tank factor of 50,000 meters (denoted situation 2). As for the initial pressure of these possible situations, the best solutions occur at a $p_{initial}$ of 277,169,245 Pa (40,200 psi) for both situations. This results in a tank mass of 3,889,790.17 kg (8,578,448.8 lbs) for situation 1 and 777,958.03kg (1,715,689.8 lbs) for situation 2.

Now that the tank and pressurant masses are known, these values must be compared and implemented into the current system to check for feasibility. The easiest way to check this

feasibility is to see if the new tank system weighs the same as the old, or that the inert mass and inert mass fraction for each system are the same. Table 3.4 shows a rough comparison of all of the systems' pressurant system masses (a detailed mass breakdown is located in Table B.7-B.13, Appendix B). As viewed in Table 3.4, one can see that the modified system weighs much more

Pressurant Test Summary
Table 3.4

Pressurant	Helium	Nitrogen	Argon	Current System
Optimal $p_{initial}$ (Pa)	277,169,245.00	343,689,863.80	277,169,245.00	
$m_{pressurant}$ (kg)	616,216.57	3,234,838.23	6,216,035.63	
φ_{tank}=10,000m				
m_{tank} (kg)	3,889,790.17	2,908,650.46	3,927,571.38	
m_{launch} (kg)	8,166,371.37	9,803,853.32	13,803,971.64	**2,040,469**
ΔV_{tot} (m/s)	795.9130161	645.6914563	442.2510007	**9,086**
$F/W_{lift\text{-}off\text{-}1}$	0.376008828	0.313206208	0.222445236	**1.5**
$F/W_{lift\text{-}off\text{-}2}$	0.097164998	0.078404009	0.053275382	
φ_{tank}=50,000m				
m_{tank} (kg)	777,958.03	581,730.09	785,514.28	
m_{launch} (kg)	5,054,539.24	7,476,932.95	10,661,914.54	**2,040,469**
ΔV_{tot} (m/s)	1433.657314	882.5220218	587.6493267	**9,086**
$F/W_{lift\text{-}off\text{-}1}$	0.607499038	0.410680121	0.287999657	**1.5**
$F/W_{lift\text{-}off\text{-}2}$	0.178197311	0.108050911	0.0712001	

than the current system. This can be attributed to the pressurant tank and the pressurant mass itself. The pressurant is considered inert mass and remains with the system for the duration of the launch. This situation puts a great burden on the launch capability of the system.

To gain a better idea of how this pressurant system limits the launch capability, the change in velocity (ΔV) for the modified system is calculated using the ideal rocket equation (equation 3.5) and compared to the required ΔV.

$$\Delta V = I_{sp} g_o \ln\left(\frac{m_i}{m_f}\right) \qquad \text{(equation 3.5)}$$

Once again it is seen that large inert mass due to the pressurant and the tanks greatly reduces the total ΔV to 795.91 m/s for situation 1 and 1433.66 m/s for situation 2. These values are well below the required ΔV of 9,086 m/s [5].

Another characteristic of great importance is the thrust-to-weight ratio, F/W, for each stage. If the F/W is less than one, the system will never lift off. In addition a margin for losses (i.e. drag) should be included which increases the F/W to about 1.5 for the shuttle at lift-off. As demonstrated by the values in Table 3.4, none of the test systems can even get off of the launch pad. The best F/W is .607 for stage 1 situation 2 with helium pressurant. In addition, an interesting fact is noted; because of the large amount of inert mass (pressurant and tank) that remains with the shuttle throughout launch, the F/W becomes greatly reduced at the beginning of stage 2 (after SRM separation).

Based on the aforementioned material, this method of simply replacing the turbo-pumps with a pressurant tank does not work. The three tanks, fuel tank, oxidizer tank, pressurant tank, provide a large source of inert mass as a result of the required high chamber pressure of the SSME's. In addition, even if the tanks themselves had an outstanding tank factor (low mass) the pressurant needed to fill all the tanks and maintain an operating pressure is extremely high. The pressurant accounts for a large portion of the inert mass, which cannot be reduced unless the tank volumes are reduced. This was done through pressure optimization for the pressurant tank. However, the propellants are liquids and their volumes cannot be simply reduced by increasing

the tank pressure. The amount of propellant must be reduced in order to reduce the tank volumes. This is possible by staging the shuttle launch system. This is the topic of the next sections.

3.2 Staging STS

This next section presents a possible solution that was present in the previous section. How can the volume of the propellant tanks be reduced. One possible solution is staging the current system. By staging the launch system, the amount of propellant needed to obtain the required ΔV can be reduced. Various staging methods will be performed to investigate the feasibility of the idea. One drawback of this solution is the need for research, development, design, and testing of the new system. In addition, staging the system in a manner different than the current system adds complexity.

Once again, the constraints include no modification to the SRM's or to the orbiter. In addition, the payload capability cannot be reduced to allow for an increase in launch system mass.

The process by which this staging method is tested is very simple, and is utilized in the follwing sections to test the different situations. The process is explained in Algorithm 3.2.

Algorithm 3.2: Mass (Isp, m_{pay}, ΔV_{tot} , f_{inert} $\Rightarrow$ m_I , m_f, m_{prop} ,m_{inert} , F/W)

1. Choose a reasonable inert mass fraction, f_{inert}, where:

$$f_{inert} = \frac{m_{inert}}{m_{inert} + m_{prop}} \qquad \text{(equation 3.6)}$$

- Usually f_{inert} = 0.06 to 0.20 for most systems.

2. Find propellant mass, m_{prop}, from equation 3.7:

$$m_{prop} = \frac{m_{pay}\left(e^{\left(\frac{\Delta V_{tot}}{I_{sp}g_o}\right)} - 1\right)(1 - f_{inert})}{1 - f_{inert}e^{\left(\frac{\Delta V}{I_{sp}g_o}\right)}} \qquad \text{(equation3.7)}$$

3. Using f_{inert} and m_{prop}, find the inert mass, m_{inert}, from equation 3.8:

$$m_{inert} = \frac{f_{inert}}{1 - f_{inert}} m_{prop} \qquad \text{(equation 3.8)}$$

- For this investigation, m_{inert} includes the mass of the propellant tanks, intertank, external hardware, and thermal protection; the SSME's are not included, for they are a part of the payload (orbiter mass).

4. Find the initial mass, m_i, and the final mass, m_f, using equations 3.9 and 3.10, respectively:

$$m_i = m_{pay} + m_{inert} + m_{prop} = m_f + m_{prop} \qquad \text{(equation 3.9)}$$
$$m_f = m_{pay} + m_{inert} \qquad \text{(equation 3.10)}$$

5. With the initial mass, calculate the initial thrust-to-weight ratio, F/W:

$$\frac{F}{W} = \frac{T}{m_i g_o} \qquad \text{(equation 3.11)}$$

- Ensure that the F/W is greater than 1, otherwise the vehicle cannot liftoff. To account for losses (i.e. drag), a F/W of 1.3-1.5 is preferred (the current shuttle system is approximately 1.5)

3.2.b SRM's in Series with SSME's

One possible staging method is based on the fact that engines firing in series (basic staging method) is more efficient than engines firing in parallel (SRM's and SSME's firing together). With this approach, a saving is made. Once again, there are a couple of constraints:

1. The SRM's and orbiter are not modified in any way.
2. The Propellants for the SSME's are Liquid Oxygen and Liquid Hydrogen
3. For stage one, the $F/W \geq 1.3$; for the following stages (stage 2a & 2b), $F/W \geq 1.3$.

These constraints are few, but very limiting. In addition, one more major thing is considered; the modified system needs to remain simple; this reduces complexity and cost due to design and testing.

To determine the validity and possibility of this staging solution, a modified version of Algorithm 3.2 is utilized. To begin, the total propellant mass, $m_{prop\text{-}SRM\text{-}tot}$, and specific impulse at sea level, Isp_{SRM}, are obtained from Table 2.4. With these values and equations 3.5, 3.9, and 3.10, the payload mass, m_{pay}, is determined for fractions of ΔV contributed by stage one. Looking at Table C.3 and Chart C.3 in the Appendix B, the $\Delta V_{1\text{-}fract}$ for the optimal $m_{pay\text{-}1}$ is chosen. However, the best $\Delta V_{1\text{-}fract}$ must chosen with some consideration. As previously mentioned, the F/W must be greater than or equal to 1.30 for stage one. And judging from Table C.3 and Chart C.3, the best solution occurs for $\Delta V_{1\text{-}fract}$ equal to .01, which will not help the

situation at all. Therefore, $\Delta V_{1\text{-fract}} = 0.20$ is the best choice (this is where F/W=1.30). At this point $\Delta V_1 = 1{,}846$ m/s, $\Delta V_2 = 7384$ m/s, and $m_{pay-1} = 673{,}996$kg.

Once the $\Delta V_{1\text{-fract}}$ is chosen, ΔV_2 is calculated from the $\Delta V_{tot} - \Delta V_1$. With the total change in velocity required by the second stage, ΔV_2, and the mass limitation of the second stage, an optimization is performed. Using Algorithm 3.2 and starting with stage 2b, the initial mass, m_{i-2b} is calculated for this stage. In this situation, the payload is the aforementioned orbiter and its payload. The initial mass for stage 2b is then, used for the payload mass of stage 2a, m_{pay-2a}. Once again, Algorithm 3.2 is utilized. This scenario is repeat over a range of ΔV fraction for stage 2a, $\Delta V_{2a\text{-fract}}$. The optimal solution is chosen for stage 2 based on the results in Table C.4 and Chart C.4. Four main things are considered when choosing the best solution: F/W_{2a}, F/W_{2b}, and m_{i-2a}, and the f_{inert} for each stage The thrust-to-weight ratios must be at least 1.30. In addition, the initial mass for stage 2a can not exceed the payload mass allowed by stage 1. Finally an f_{inert} must be chosen that allows a possible solution. For this case, the highest possible finert that allows a solution is 0.04 for stage 2a and 0.05 for stage 2b. Although this is not a good choice (a much higher f_{inert} is better, possibly $f_{inert} = 0.20$), it is the best one which still allows some viable answer. Looking at Chart C.4, and taking into account the trends and slopes of each variable, the best solution occurs for $\Delta V_{2a} = .56$. This choice provides an $m_{i-2a} = 637{,}756$ kg, a $F/W_{2a} = 1.04$, and a $F/W_{2b} = 2.86$. The initial mass is within the limits, as well as the F/W for stage 2b. However, the f_{inert} for each stage is very low, and the F/W for stage 2a is also well below the requirement.

Without even calculating the tank masses and sizes for this situation, it is determined that this situation will not work. This is mainly because of the F/W of stage 2a and the inert mass fractions. As seen from Section 3.1, the pressurant tank and pressurant would devour the inert mass alone. This solution is the best thus far, but falls short of staying within the constraints.

3.2.c SRM's in Series with SSME's with Added Engines

This next option is similar to the situation presented in the previous section; in this situation an engine is added to 2a. This option increases the F/W of the stage, but at the same time increases the complexity. To minimize this complexity, the SSME engines are used. Using the same process utilized in section 3.2.b and maintaining the same ΔV fraction between stages 1 and 2, the best answer is determined and illustrated in Table 3.7 for stages 2a and 2b. Detailed tables and charts are located in Appendix C (Table C.3 & C.5, Chart C.3 & C.5).

Mass Values fro Section 3.2.c
Table 3.7

	Stage 1	Stage 2a	Stage 2b
ΔV_{fract}	0.20	0.41	0.59
ΔV (m/s)	1,846.00	3027.44	4,356.56
m_{prop} (kg)	997,562.00	328,633.09	193,231.66
m_{inert} (kg)	174,120.00	28,576.79	12,333.94
m_i (kg)	1,845,678.84	667,275.48	310,065.59
m_f (kg)	848,116.84	338,642.38	116,833.94
F/W	1.30	1.328625212	2.14

Once again, the f_{inert} appears to be the limiting factor of this situation. The highest finert's possible, while maintaining the initial mass limit (determined by stage 1, see section 3.2.b), were 0.08 and 0.06 for stages 2a and 2b, respectively. The initial mass and F/W for both stages are within the limitations. However, this situation will most likely not work because of the limiting inert mass, and is tested much the same way as in section 3.1

Using the same steps as in section 3.1, the tank masses and pressurant mass are calculated (Tables C.6 & C.7). With these tank masses, and the known thrusts and Isp's, the F/W and ΔV for each stage is calculated (Table C.8). Looking at the values within Table C.8, it is seen that the overall ΔV is only 2,097 m/s, which is well short of the 9,230 m/s. In addition, the F/W for each stage is never greater than 1, much less the required 1.3.

As a result, the system investigated in section 3.2.c has potential, but once again is greatly limited by the high inert mass of the tanks and pressurant. The delta V and F/W fall very short of the required amounts.

4.0 Conclusion

Pressure feeding the space shuttle main engines might first appear to be any easy solution to reducing the complexity and cost of the current turbo pump system. However, from the calculations and their resultant values, it is determined that this system is not a viable solution. Pressure systems, especially for large launch systems like the STS have a major disadvantage, the pressurant mass and tank masses. As a result of the high pressure required to operate the SSME's, the propellant tanks and pressurant tank must be able to contain very high pressure liquids. Because of this, the tanks and must be very thick, hence contributing to a large inert mass. In addition, the pressurant used, must be able to fill all of the tanks while still maintaining the required operating pressure throughout the duration of SSME operation. This necessity contributes to the inert mass of the system through the large amount of pressurant or pressurant mass. In conclusion, the system proposed and investigated within this report is not plausible.

For this system to work within the constraints, both higher tank factors and high thrusting boosters must be developed.

Some possible further investigation in this area might include looking into pressurizing the rocket propellants through their own vapor pressure. This would add propellant mass, however, the pressurant and pressurant tank would be totally eliminated. Another possible solution would be to reduce the operating pressure of the SSME's. Consequently, the nozzle throat would increase and a small hit in Isp might result. These options, though, are some alternative solutions that could be investigated.

5.0 Bibliography

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[9] Lawrence Livermoore Laboratories.

APPENDIX B

CHART B.1

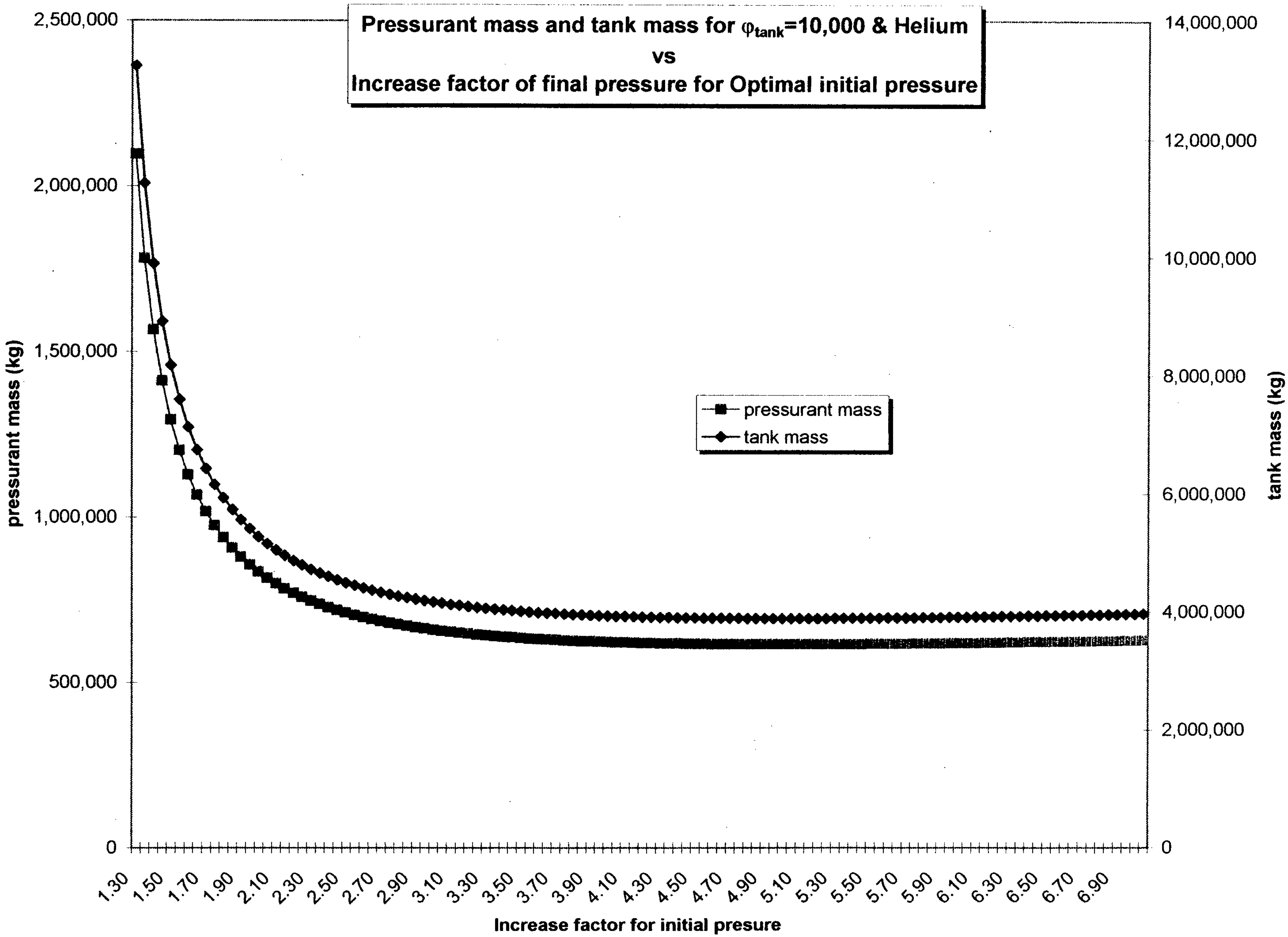
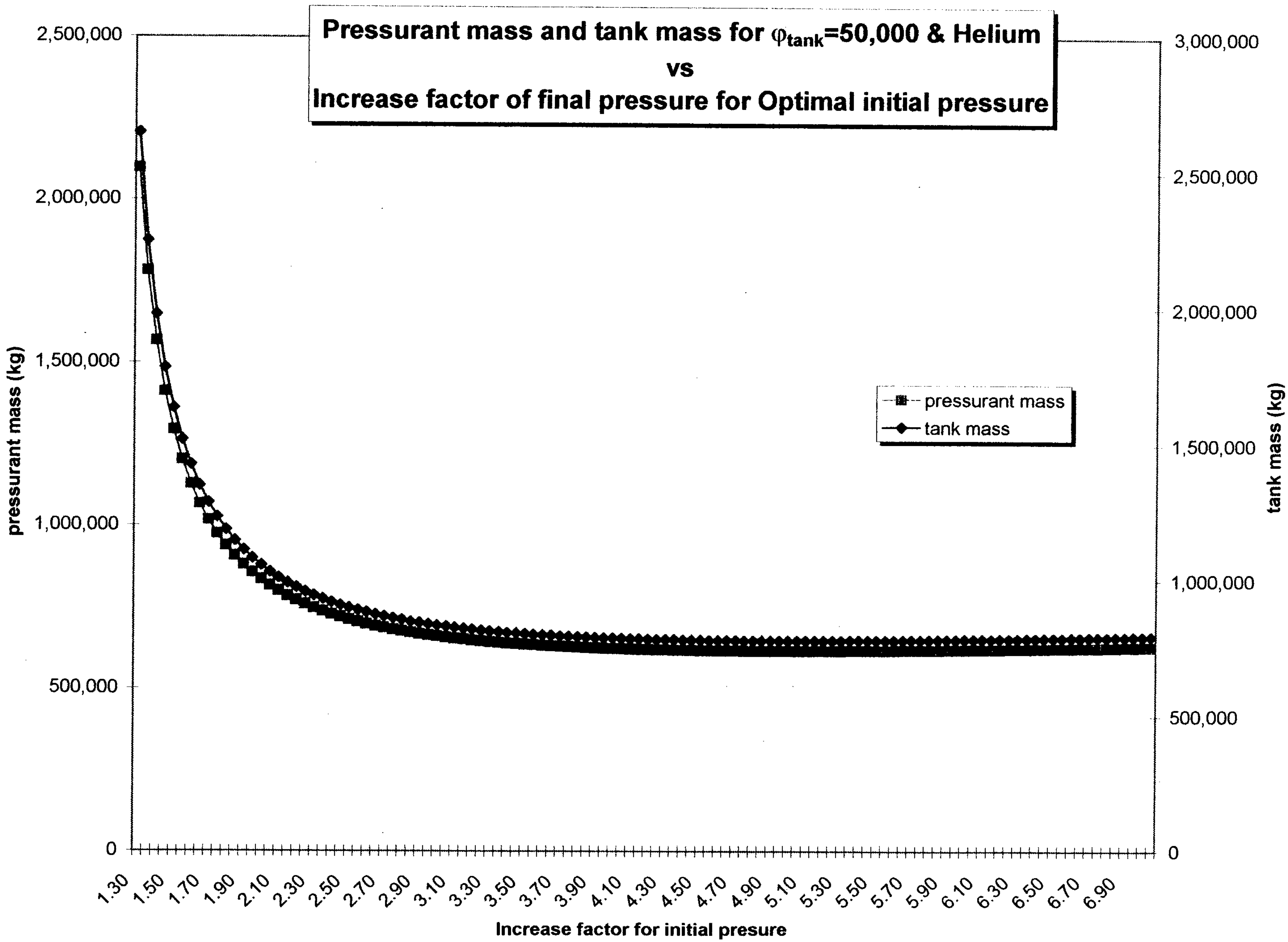
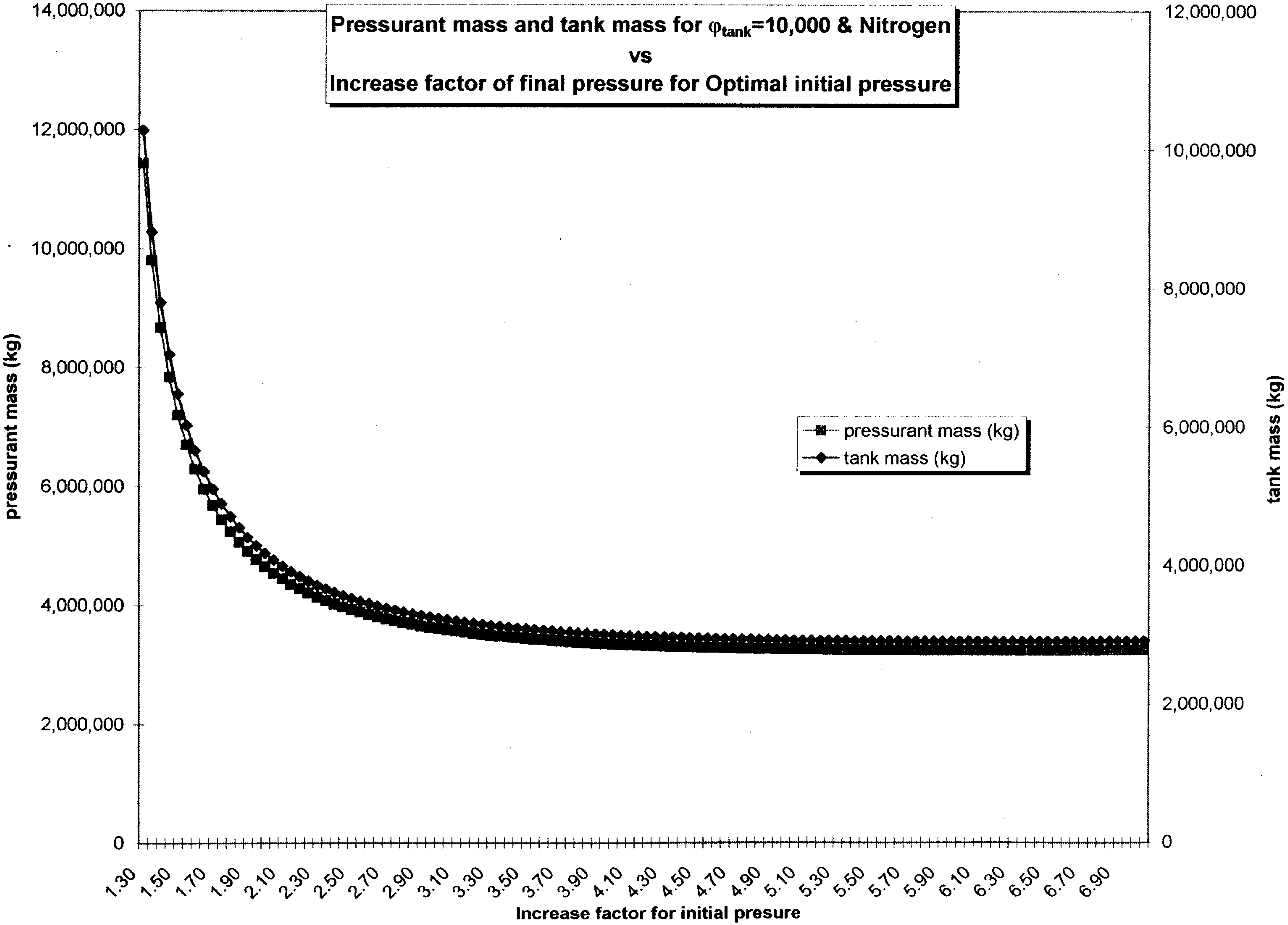

Pressurant mass and tank mass for φ_{tank}=10,000 & Helium
vs
Increase factor of final pressure for Optimal initial pressure
pressurant mass (kg)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
tank mass (kg)
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
pressurant mass
tank mass
1.30 1.50 1.70 1.90 2.10 2.30 2.50 2.70 2.90 3.10 3.30 3.50 3.70 3.90 4.10 4.30 4.50 4.70 4.90 5.10 5.30 5.50 5.70 5.90 6.10 6.30 6.50 6.70 6.90
Increase factor for initial presure

CHART B.2



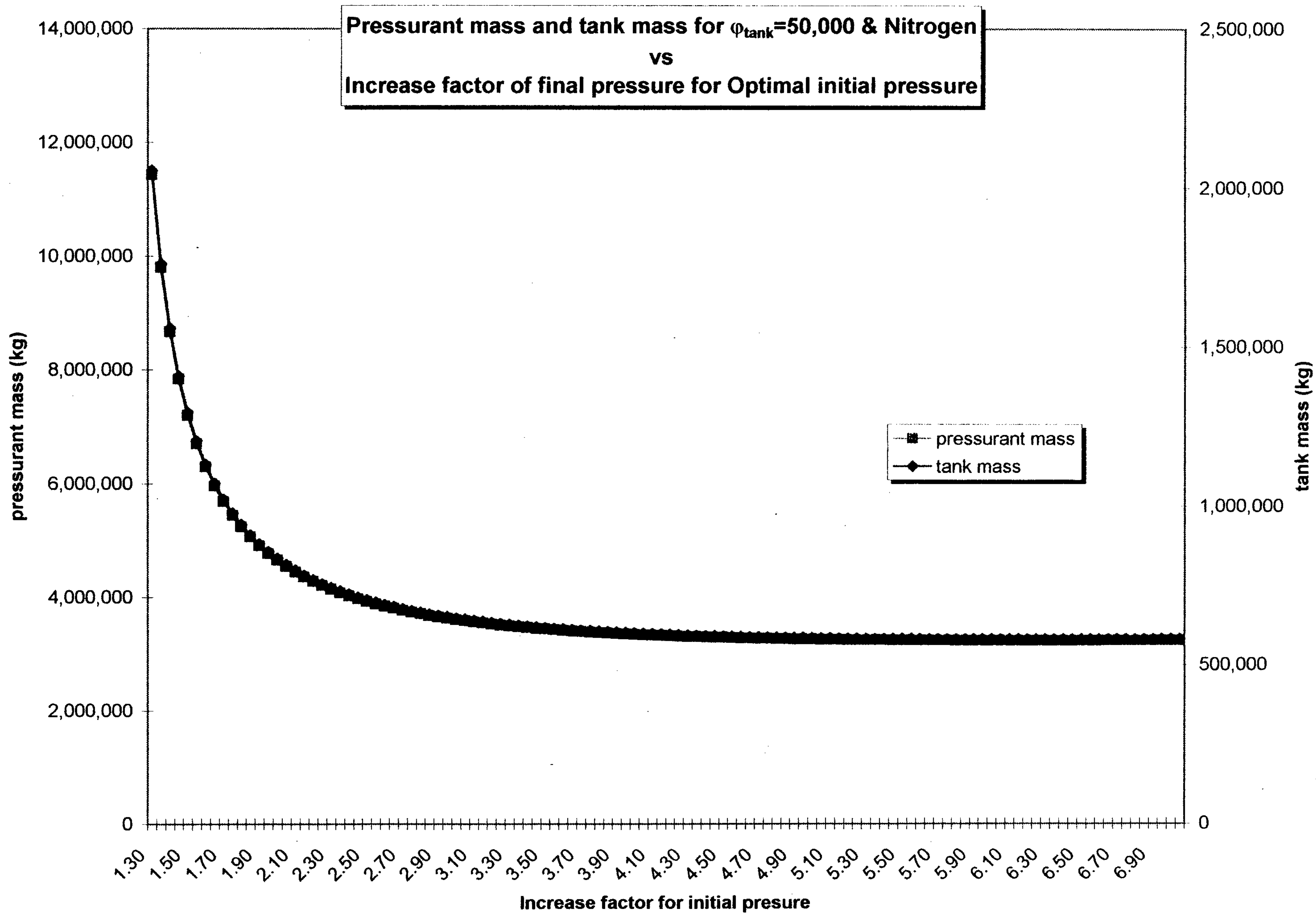
Pressurant mass and tank mass for φtank=50,000 & Helium
vs
Increase factor of final pressure for Optimal initial pressure
pressurant mass (kg)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
tank mass (kg)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
pressurant mass
tank mass
1.30
1.50
1.70
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
3.70
3.90
4.10
4.30
4.50
4.70
4.90
5.10
5.30
5.50
5.70
5.90
6.10
6.30
6.50
6.70
6.90
Increase factor for initial presure

CHART B.3



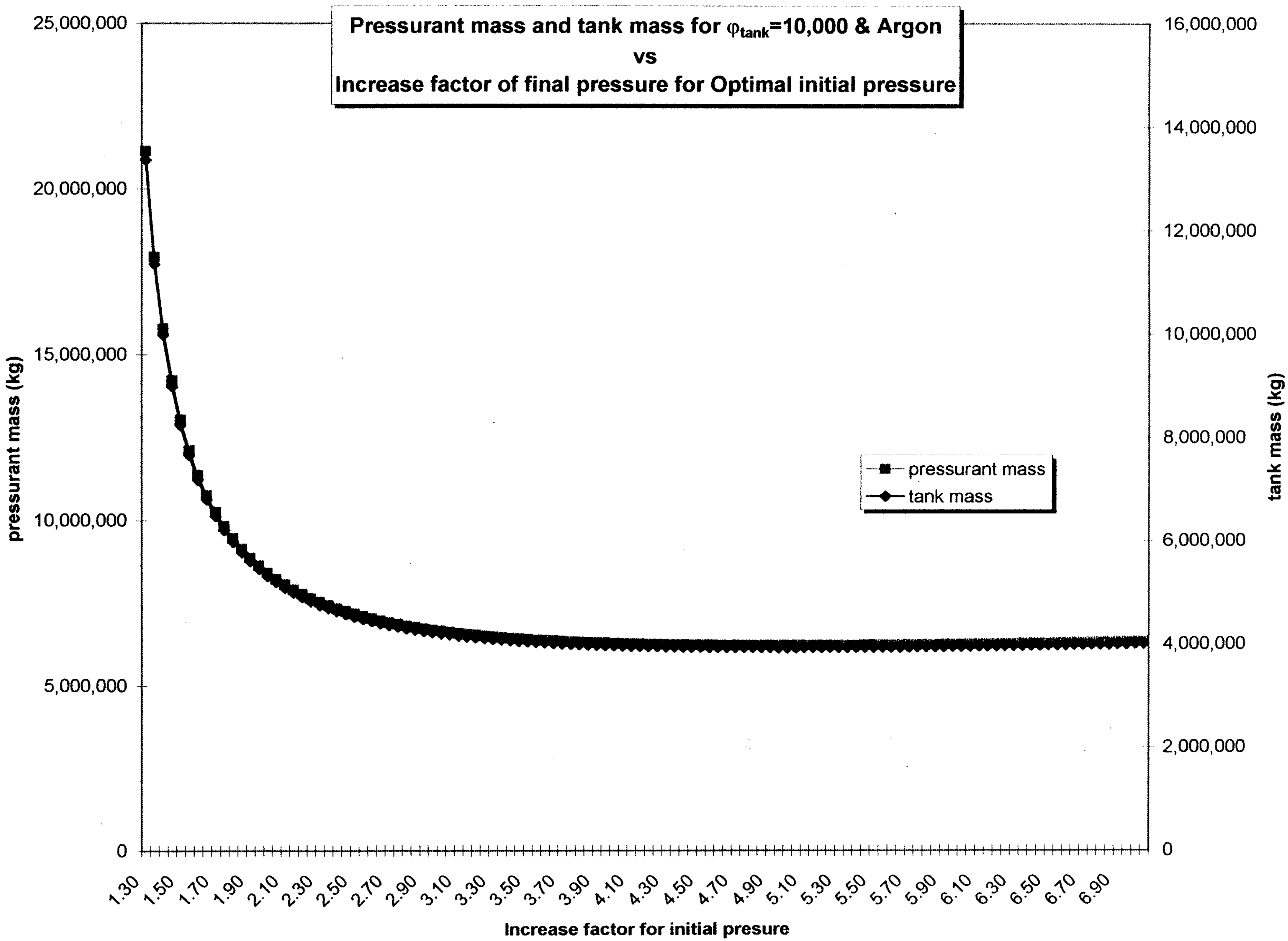
Pressurant mass and tank mass for φ_{tank}=10,000 & Nitrogen
vs
Increase factor of final pressure for Optimal initial pressure
pressurant mass (kg)
tank mass (kg)
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1.30 1.50 1.70 1.90 2.10 2.30 2.50 2.70 2.90 3.10 3.30 3.50 3.70 3.90 4.10 4.30 4.50 4.70 4.90 5.10 5.30 5.50 5.70 5.90 6.10 6.30 6.50 6.70 6.90
Increase factor for initial presure

CHART B.4



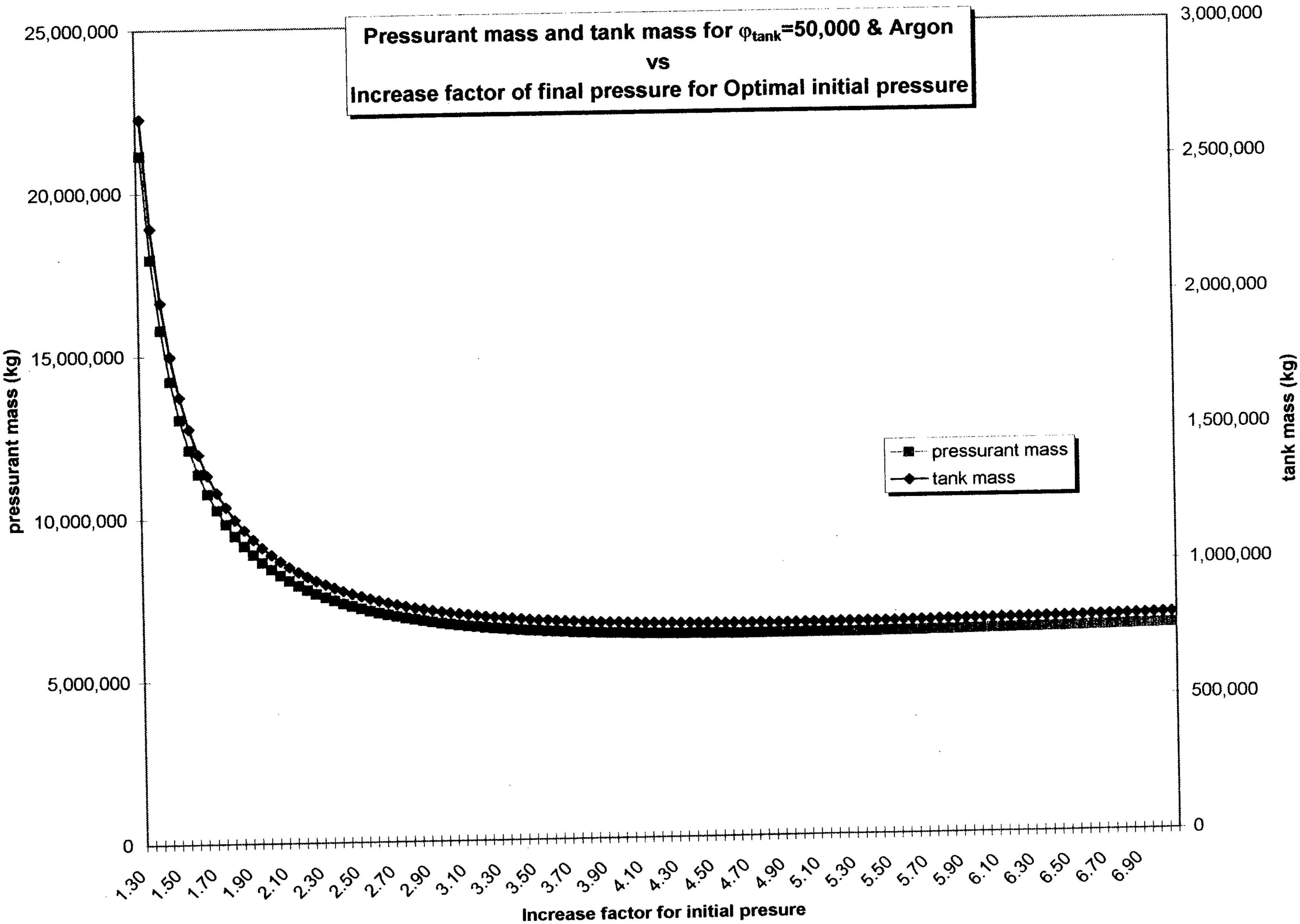
Pressurant mass and tank mass for φ_{tank}=50,000 & Nitrogen
vs
Increase factor of final pressure for Optimal initial pressure
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
pressurant mass (kg)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
tank mass (kg)
pressurant mass
tank mass
1.30
1.50
1.70
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
3.70
3.90
4.10
4.30
4.50
4.70
4.90
5.10
5.30
5.50
5.70
5.90
6.10
6.30
6.50
6.70
6.90
Increase factor for initial presure

CHART B.5



Pressurant mass and tank mass for φ_{tank}=10,000 & Argon
vs
Increase factor of final pressure for Optimal initial pressure
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
pressurant mass (kg)
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
tank mass (kg)
pressurant mass
tank mass
1.30
1.50
1.70
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
3.70
3.90
4.10
4.30
4.50
4.70
4.90
5.10
5.30
5.50
5.70
5.90
6.10
6.30
6.50
6.70
6.90
Increase factor for initial presure

CHART B.6



Pressurant mass and tank mass for φ_{tank}=50,000 & Argon
vs
Increase factor of final pressure for Optimal initial pressure
pressurant mass (kg)
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
tank mass (kg)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
pressurant mass
tank mass
1.30
1.50
1.70
1.90
2.10
2.30
2.50
2.70
2.90
3.10
3.30
3.50
3.70
3.90
4.10
4.30
4.50
4.70
4.90
5.10
5.30
5.50
5.70
5.90
6.10
6.30
6.50
6.70
6.90
Increase factor for initial presure

CHART B.1

$Pressure_{initial}$ Test for Helium

gamma	1.66		
R (J/kg-K)	2,078.00	Critical Temp (K)	126.20
p_{needed} (Pa)	55,433,849	**Tank Factor**	**10,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	568.26		
Vol_{LH} (m^3)	1,512.23		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	$State_{final}$ Test
18,020	20,101	21,106	298	1.30	72,064,004	268	2,097,086	18,020	13,237,594	0.00	GAS
14,744	16,825	17,666	298	1.35	74,835,696	264	1,781,863	14,744	11,247,786	0.00	GAS
12,505	14,585	15,314	298	1.40	77,607,389	261	1,567,141	12,505	9,892,381	0.00	GAS
10,876	12,956	13,604	298	1.45	80,379,081	257	1,411,680	10,876	8,911,051	0.00	GAS
9,637	11,718	12,304	298	1.50	83,150,774	254	1,294,083	9,637	8,168,740	0.00	GAS
8,664	10,744	11,282	298	1.55	85,922,466	250	1,202,147	8,664	7,588,402	0.00	GAS
7,878	9,959	10,457	298	1.60	88,694,158	247	1,128,399	7,878	7,122,877	0.00	GAS
7,231	9,311	9,777	298	1.65	91,465,851	244	1,068,010	7,231	6,741,683	0.00	GAS
6,688	8,768	9,206	298	1.70	94,237,543	241	1,017,722	6,688	6,424,240	0.00	GAS
6,225	8,306	8,721	298	1.75	97,009,236	239	975,252	6,225	6,156,156	0.00	GAS
5,827	7,908	8,303	298	1.80	99,780,928	236	938,959	5,827	5,927,058	0.00	GAS
5,481	7,561	7,939	298	1.85	102,552,621	233	907,628	5,481	5,729,288	0.00	GAS
5,176	7,256	7,619	298	1.90	105,324,313	231	880,344	5,176	5,557,064	0.00	GAS
4,906	6,987	7,336	298	1.95	108,096,006	229	856,404	4,906	5,405,941	0.00	GAS
4,665	6,746	7,083	298	2.00	110,867,698	226	835,256	4,665	5,272,446	0.00	GAS
4,449	6,530	6,856	298	2.05	113,639,390	224	816,464	4,449	5,153,826	0.00	GAS
4,254	6,334	6,651	298	2.10	116,411,083	222	799,679	4,254	5,047,871	0.00	GAS
4,077	6,157	6,465	298	2.15	119,182,775	220	784,615	4,077	4,952,785	0.00	GAS
3,915	5,996	6,295	298	2.20	121,954,468	218	771,040	3,915	4,867,095	0.00	GAS
3,767	5,848	6,140	298	2.25	124,726,160	216	758,761	3,767	4,789,581	0.00	GAS
3,631	5,712	5,997	298	2.30	127,497,853	214	747,615	3,631	4,719,225	0.00	GAS
3,506	5,586	5,865	298	2.35	130,269,545	212	737,467	3,506	4,655,170	0.00	GAS
3,389	5,470	5,743	298	2.40	133,041,238	210	728,203	3,389	4,596,688	0.00	GAS
3,282	5,362	5,630	298	2.45	135,812,930	209	719,723	3,282	4,543,159	0.00	GAS
3,181	5,262	5,525	298	2.50	138,584,623	207	711,943	3,181	4,494,051	0.00	GAS
3,087	5,168	5,426	298	2.55	141,356,315	205	704,791	3,087	4,448,905	0.00	GAS
3,000	5,080	5,334	298	2.60	144,128,007	204	698,203	3,000	4,407,322	0.00	GAS
2,918	4,998	5,248	298	2.65	146,899,700	202	692,125	2,918	4,368,954	0.00	GAS
2,840	4,921	5,167	298	2.70	149,671,392	201	686,508	2,840	4,333,497	0.00	GAS
2,768	4,848	5,090	298	2.75	152,443,085	199	681,310	2,768	4,300,684	0.00	GAS
2,699	4,779	5,018	298	2.80	155,214,777	198	676,493	2,699	4,270,279	0.00	GAS
2,634	4,715	4,950	298	2.85	157,986,470	197	672,025	2,634	4,242,071	0.00	GAS
2,573	4,653	4,886	298	2.90	160,758,162	195	667,875	2,573	4,215,876	0.00	GAS
2,514	4,595	4,825	298	2.95	163,529,855	194	664,017	2,514	4,191,526	0.00	GAS
2,459	4,540	4,767	298	3.00	166,301,547	193	660,429	2,459	4,168,873	0.00	GAS
2,407	4,487	4,711	298	3.05	169,073,239	191	657,088	2,407	4,147,784	0.00	GAS
2,357	4,437	4,659	298	3.10	171,844,932	190	653,975	2,357	4,128,138	0.00	GAS
2,309	4,389	4,609	298	3.15	174,616,624	189	651,075	2,309	4,109,828	0.00	GAS
2,263	4,344	4,561	298	3.20	177,388,317	188	648,370	2,263	4,092,755	0.00	GAS
2,220	4,300	4,515	298	3.25	180,160,009	187	645,847	2,220	4,076,830	0.00	GAS
2,178	4,259	4,472	298	3.30	182,931,702	185	643,494	2,178	4,061,973	0.00	GAS
2,138	4,219	4,430	298	3.35	185,703,394	184	641,297	2,138	4,048,109	0.00	GAS
2,100	4,181	4,390	298	3.40	188,475,087	183	639,248	2,100	4,035,173	0.00	GAS
2,064	4,144	4,351	298	3.45	191,246,779	182	637,336	2,064	4,023,101	0.00	GAS
2,028	4,109	4,314	298	3.50	194,018,472	181	635,551	2,028	4,011,839	0.00	GAS
1,995	4,075	4,279	298	3.55	196,790,164	180	633,887	1,995	4,001,334	0.00	GAS
1,962	4,043	4,245	298	3.60	199,561,856	179	632,335	1,962	3,991,539	0.00	GAS
1,931	4,011	4,212	298	3.65	202,333,549	178	630,889	1,931	3,982,409	0.00	GAS
1,901	3,981	4,180	298	3.70	205,105,241	177	629,542	1,901	3,973,906	0.00	GAS
1,872	3,952	4,150	298	3.75	207,876,934	176	628,288	1,872	3,965,991	0.00	GAS
1,844	3,924	4,120	298	3.80	210,648,626	175	627,122	1,844	3,958,630	0.00	GAS
1,816	3,897	4,092	298	3.85	213,420,319	174	626,039	1,816	3,951,791	0.00	GAS
1,790	3,871	4,064	298	3.90	216,192,011	173	625,033	1,790	3,945,444	0.00	GAS

CHART B.1

1,765	3,845	4,038	298	3.95	218,963,704	173	624,101	1,765	3,939,562	0.00 GAS
1,741	3,821	4,012	298	4.00	221,735,396	172	623,239	1,741	3,934,118	0.00 GAS
1,717	3,797	3,987	298	4.05	224,507,088	171	622,443	1,717	3,929,091	0.00 GAS
1,694	3,774	3,963	298	4.10	227,278,781	170	621,708	1,694	3,924,456	0.00 GAS
1,672	3,752	3,940	298	4.15	230,050,473	169	621,033	1,672	3,920,193	0.00 GAS
1,650	3,731	3,917	298	4.20	232,822,166	168	620,414	1,650	3,916,283	0.00 GAS
1,629	3,710	3,895	298	4.25	235,593,858	168	619,847	1,629	3,912,708	0.00 GAS
1,609	3,689	3,874	298	4.30	238,365,551	167	619,331	1,609	3,909,451	0.00 GAS
1,589	3,670	3,853	298	4.35	241,137,243	166	618,863	1,589	3,906,495	0.00 GAS
1,570	3,651	3,833	298	4.40	243,908,936	165	618,440	1,570	3,903,826	0.00 GAS
1,552	3,632	3,814	298	4.45	246,680,628	165	618,060	1,552	3,901,430	0.00 GAS
1,533	3,614	3,795	298	4.50	249,452,321	164	617,722	1,533	3,899,293	0.00 GAS
1,516	3,596	3,776	298	4.55	252,224,013	163	617,423	1,516	3,897,403	0.00 GAS
1,499	3,579	3,758	298	4.60	254,995,705	162	617,161	1,499	3,895,749	0.00 GAS
1,482	3,563	3,741	298	4.65	257,767,398	162	616,934	1,482	3,894,319	0.00 GAS
1,466	3,546	3,724	298	4.70	260,539,090	161	616,741	1,466	3,893,103	0.00 GAS
1,450	3,531	3,707	298	4.75	263,310,783	160	616,581	1,450	3,892,092	0.00 GAS
1,435	3,515	3,691	298	4.80	266,082,475	160	616,452	1,435	3,891,275	0.00 GAS
1,420	3,500	3,675	298	4.85	268,854,168	159	616,352	1,420	3,890,645	0.00 GAS
1,405	3,485	3,660	298	4.90	271,625,860	158	616,280	1,405	3,890,192	0.00 GAS
1,391	3,471	3,645	298	4.95	274,397,553	158	616,236	1,391	3,889,910	0.00 GAS
1,377	[illegible]	3,630	298	5.00	277,169,245	157	616,217	1,377	3,889,790	0.00 GAS
1,363	3,444	3,616	298	5.05	279,940,937	157	616,222	1,363	3,889,826	0.00 GAS
1,350	3,430	3,602	298	5.10	282,712,630	156	616,252	1,350	3,890,011	0.00 GAS
1,337	3,417	3,588	298	5.15	285,484,322	155	616,303	1,337	3,890,339	0.00 GAS
1,324	3,405	3,575	298	5.20	288,256,015	155	616,377	1,324	3,890,803	0.00 GAS
1,312	3,392	3,562	298	5.25	291,027,707	154	616,471	1,312	3,891,398	0.00 GAS
1,300	3,380	3,549	298	5.30	293,799,400	154	616,586	1,300	3,892,119	0.00 GAS
1,288	3,368	3,537	298	5.35	296,571,092	153	616,719	1,288	3,892,960	0.00 GAS
1,276	3,357	3,524	298	5.40	299,342,785	152	616,870	1,276	3,893,917	0.00 GAS
1,265	3,345	3,512	298	5.45	302,114,477	152	617,039	1,265	3,894,984	0.00 GAS
1,254	3,334	3,501	298	5.50	304,886,169	151	617,225	1,254	3,896,158	0.00 GAS
1,243	3,323	3,489	298	5.55	307,657,862	151	617,428	1,243	3,897,434	0.00 GAS
1,232	3,313	3,478	298	5.60	310,429,554	150	617,645	1,232	3,898,808	0.00 GAS
1,222	3,302	3,467	298	5.65	313,201,247	150	617,878	1,222	3,900,276	0.00 GAS
1,211	3,292	3,456	298	5.70	315,972,939	149	618,125	1,211	3,901,835	0.00 GAS
1,201	3,282	3,446	298	5.75	318,744,632	149	618,385	1,201	3,903,480	0.00 GAS
1,192	3,272	3,436	298	5.80	321,516,324	148	618,659	1,192	3,905,210	0.00 GAS
1,182	3,262	3,426	298	5.85	324,288,017	148	618,946	1,182	3,907,019	0.00 GAS
1,172	3,253	3,416	298	5.90	327,059,709	147	619,245	1,172	3,908,906	0.00 GAS
1,163	3,244	3,406	298	5.95	329,831,402	147	619,556	1,163	3,910,868	0.00 GAS
1,154	3,235	3,396	298	6.00	332,603,094	146	619,878	1,154	3,912,901	0.00 GAS
1,145	3,226	3,387	298	6.05	335,374,786	146	620,211	1,145	3,915,003	0.00 GAS
1,136	3,217	3,378	298	6.10	338,146,479	145	620,554	1,136	3,917,171	0.00 GAS
1,128	3,208	3,369	298	6.15	340,918,171	145	620,908	1,128	3,919,403	0.00 GAS
1,119	3,200	3,360	298	6.20	343,689,864	144	621,271	1,119	3,921,697	0.00 GAS
1,111	3,192	3,351	298	6.25	346,461,556	144	621,644	1,111	3,924,050	0.00 GAS
1,103	3,183	3,343	298	6.30	349,233,249	143	622,026	1,103	3,926,460	0.00 GAS
1,095	3,175	3,334	298	6.35	352,004,941	143	622,416	1,095	3,928,925	0.00 GAS
1,087	3,168	3,326	298	6.40	354,776,634	142	622,815	1,087	3,931,443	0.00 GAS
1,079	3,160	3,318	298	6.45	357,548,326	142	623,222	1,079	3,934,012	0.00 GAS
1,072	3,152	3,310	298	6.50	360,320,018	142	623,637	1,072	3,936,630	0.00 GAS
1,064	3,145	3,302	298	6.55	363,091,711	141	624,059	1,064	3,939,296	0.00 GAS
1,057	3,137	3,294	298	6.60	365,863,403	141	624,489	1,057	3,942,007	0.00 GAS
1,050	3,130	3,287	298	6.65	368,635,096	140	624,925	1,050	3,944,763	0.00 GAS
1,043	3,123	3,279	298	6.70	371,406,788	140	625,369	1,043	3,947,561	0.00 GAS
1,036	3,116	3,272	298	6.75	374,178,481	139	625,818	1,036	3,950,400	0.00 GAS
1,029	3,109	3,265	298	6.80	376,950,173	139	626,274	1,029	3,953,278	0.00 GAS
1,022	3,103	3,258	298	6.85	379,721,866	139	626,736	1,022	3,956,195	0.00 GAS
1,015	3,096	3,251	298	6.90	382,493,558	138	627,204	1,015	3,959,148	0.00 GAS
1,009	3,089	3,244	298	6.95	385,265,251	138	627,678	1,009	3,962,137	0.00 GAS
1,002	3,083	3,237	298	7.00	388,036,943	137	628,157	1,002	3,965,161	0.00 GAS
996	3,077	3,230	298	7.05	390,808,635	137	628,641	996	3,968,217	0.00 GAS

TABLE B.2

$Pressure_{initial}$ Test for Helium

gamma	1.66		
R (J/kg-K)	2,078.00	Critical Temp (K)	126.20
p_{needed} (Pa)	55,433,849	**Tank Factor**	**50,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	568.26		
Vol_{LH} (m^3)	1,512.23		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	$State_{final}$ Test
18,020	20,101	21,106	298	1.30	72,064,004	268	2,097,086	18,020	2,647,519	0.00	GAS
14,744	16,825	17,666	298	1.35	74,835,696	264	1,781,863	14,744	2,249,557	0.00	GAS
12,505	14,585	15,314	298	1.40	77,607,389	261	1,567,141	12,505	1,978,476	0.00	GAS
10,876	12,956	13,604	298	1.45	80,379,081	257	1,411,680	10,876	1,782,210	0.00	GAS
9,637	11,718	12,304	298	1.50	83,150,774	254	1,294,083	9,637	1,633,748	0.00	GAS
8,664	10,744	11,282	298	1.55	85,922,466	250	1,202,147	8,664	1,517,680	0.00	GAS
7,878	9,959	10,457	298	1.60	88,694,158	247	1,128,399	7,878	1,424,575	0.00	GAS
7,231	9,311	9,777	298	1.65	91,465,851	244	1,068,010	7,231	1,348,337	0.00	GAS
6,688	8,768	9,206	298	1.70	94,237,543	241	1,017,722	6,688	1,284,848	0.00	GAS
6,225	8,306	8,721	298	1.75	97,009,236	239	975,252	6,225	1,231,231	0.00	GAS
5,827	7,908	8,303	298	1.80	99,780,928	236	938,959	5,827	1,185,412	0.00	GAS
5,481	7,561	7,939	298	1.85	102,552,621	233	907,628	5,481	1,145,858	0.00	GAS
5,176	7,256	7,619	298	1.90	105,324,313	231	880,344	5,176	1,111,413	0.00	GAS
4,906	6,987	7,336	298	1.95	108,096,006	229	856,404	4,906	1,081,188	0.00	GAS
4,665	6,746	7,083	298	2.00	110,867,698	226	835,256	4,665	1,054,489	0.00	GAS
4,449	6,530	6,856	298	2.05	113,639,390	224	816,464	4,449	1,030,765	0.00	GAS
4,254	6,334	6,651	298	2.10	116,411,083	222	799,679	4,254	1,009,574	0.00	GAS
4,077	6,157	6,465	298	2.15	119,182,775	220	784,615	4,077	990,557	0.00	GAS
3,915	5,996	6,295	298	2.20	121,954,468	218	771,040	3,915	973,419	0.00	GAS
3,767	5,848	6,140	298	2.25	124,726,160	216	758,761	3,767	957,916	0.00	GAS
3,631	5,712	5,997	298	2.30	127,497,853	214	747,615	3,631	943,845	0.00	GAS
3,506	5,586	5,865	298	2.35	130,269,545	212	737,467	3,506	931,034	0.00	GAS
3,389	5,470	5,743	298	2.40	133,041,238	210	728,203	3,389	919,338	0.00	GAS
3,282	5,362	5,630	298	2.45	135,812,930	209	719,723	3,282	908,632	0.00	GAS
3,181	5,262	5,525	298	2.50	138,584,623	207	711,943	3,181	898,810	0.00	GAS
3,087	5,168	5,426	298	2.55	141,356,315	205	704,791	3,087	889,781	0.00	GAS
3,000	5,080	5,334	298	2.60	144,128,007	204	698,203	3,000	881,464	0.00	GAS
2,918	4,998	5,248	298	2.65	146,899,700	202	692,125	2,918	873,791	0.00	GAS
2,840	4,921	5,167	298	2.70	149,671,392	201	686,508	2,840	866,699	0.00	GAS
2,768	4,848	5,090	298	2.75	152,443,085	199	681,310	2,768	860,137	0.00	GAS
2,699	4,779	5,018	298	2.80	155,214,777	198	676,493	2,699	854,056	0.00	GAS
2,634	4,715	4,950	298	2.85	157,986,470	197	672,025	2,634	848,414	0.00	GAS
2,573	4,653	4,886	298	2.90	160,758,162	195	667,875	2,573	843,175	0.00	GAS
2,514	4,595	4,825	298	2.95	163,529,855	194	664,017	2,514	838,305	0.00	GAS
2,459	4,540	4,767	298	3.00	166,301,547	193	660,429	2,459	833,775	0.00	GAS
2,407	4,487	4,711	298	3.05	169,073,239	191	657,088	2,407	829,557	0.00	GAS
2,357	4,437	4,659	298	3.10	171,844,932	190	653,975	2,357	825,628	0.00	GAS
2,309	4,389	4,609	298	3.15	174,616,624	189	651,075	2,309	821,966	0.00	GAS
2,263	4,344	4,561	298	3.20	177,388,317	188	648,370	2,263	818,551	0.00	GAS
2,220	4,300	4,515	298	3.25	180,160,009	187	645,847	2,220	815,366	0.00	GAS
2,178	4,259	4,472	298	3.30	182,931,702	185	643,494	2,178	812,395	0.00	GAS
2,138	4,219	4,430	298	3.35	185,703,394	184	641,297	2,138	809,622	0.00	GAS
2,100	4,181	4,390	298	3.40	188,475,087	183	639,248	2,100	807,035	0.00	GAS
2,064	4,144	4,351	298	3.45	191,246,779	182	637,336	2,064	804,620	0.00	GAS
2,028	4,109	4,314	298	3.50	194,018,472	181	635,551	2,028	802,368	0.00	GAS
1,995	4,075	4,279	298	3.55	196,790,164	180	633,887	1,995	800,267	0.00	GAS
1,962	4,043	4,245	298	3.60	199,561,856	179	632,335	1,962	798,308	0.00	GAS
1,931	4,011	4,212	298	3.65	202,333,549	178	630,889	1,931	796,482	0.00	GAS
1,901	3,981	4,180	298	3.70	205,105,241	177	629,542	1,901	794,781	0.00	GAS
1,872	3,952	4,150	298	3.75	207,876,934	176	628,288	1,872	793,198	0.00	GAS
1,844	3,924	4,120	298	3.80	210,648,626	175	627,122	1,844	791,726	0.00	GAS
1,816	3,897	4,092	298	3.85	213,420,319	174	626,039	1,816	790,358	0.00	GAS
1,790	3,871	4,064	298	3.90	216,192,011	173	625,033	1,790	789,089	0.00	GAS

TABLE B.2

1,765	3,845	4,038	298	3.95	218,963,704	173	624,101	1,765	787,912	0.00 GAS
1,741	3,821	4,012	298	4.00	221,735,396	172	623,239	1,741	786,824	0.00 GAS
1,717	3,797	3,987	298	4.05	224,507,088	171	622,443	1,717	785,818	0.00 GAS
1,694	3,774	3,963	298	4.10	227,278,781	170	621,708	1,694	784,891	0.00 GAS
1,672	3,752	3,940	298	4.15	230,050,473	169	621,033	1,672	784,039	0.00 GAS
1,650	3,731	3,917	298	4.20	232,822,166	168	620,414	1,650	783,257	0.00 GAS
1,629	3,710	3,895	298	4.25	235,593,858	168	619,847	1,629	782,542	0.00 GAS
1,609	3,689	3,874	298	4.30	238,365,551	167	619,331	1,609	781,890	0.00 GAS
1,589	3,670	3,853	298	4.35	241,137,243	166	618,863	1,589	781,299	0.00 GAS
1,570	3,651	3,833	298	4.40	243,908,936	165	618,440	1,570	780,765	0.00 GAS
1,552	3,632	3,814	298	4.45	246,680,628	165	618,060	1,552	780,286	0.00 GAS
1,533	3,614	3,795	298	4.50	249,452,321	164	617,722	1,533	779,859	0.00 GAS
1,516	3,596	3,776	298	4.55	252,224,013	163	617,423	1,516	779,481	0.00 GAS
1,499	3,579	3,758	298	4.60	254,995,705	162	617,161	1,499	779,150	0.00 GAS
1,482	3,563	3,741	298	4.65	257,767,398	162	616,934	1,482	778,864	0.00 GAS
1,466	3,546	3,724	298	4.70	260,539,090	161	616,741	1,466	778,621	0.00 GAS
1,450	3,531	3,707	298	4.75	263,310,783	160	616,581	1,450	778,418	0.00 GAS
1,435	3,515	3,691	298	4.80	266,082,475	160	616,452	1,435	778,255	0.00 GAS
1,420	3,500	3,675	298	4.85	268,854,168	159	616,352	1,420	778,129	0.00 GAS
1,405	3,485	3,660	298	4.90	271,625,860	158	616,280	1,405	778,038	0.00 GAS
1,391	3,471	3,645	298	4.95	274,397,553	158	616,236	1,391	777,982	0.00 GAS
1,377	3,457	3,630	298	5.00	277,169,245	157	616,217	1,377	777,958	0.00 GAS
1,363	3,444	3,616	298	5.05	279,940,937	157	616,222	1,363	777,965	0.00 GAS
1,350	3,430	3,602	298	5.10	282,712,630	156	616,252	1,350	778,002	0.00 GAS
1,337	3,417	3,588	298	5.15	285,484,322	155	616,303	1,337	778,068	0.00 GAS
1,324	3,405	3,575	298	5.20	288,256,015	155	616,377	1,324	778,161	0.00 GAS
1,312	3,392	3,562	298	5.25	291,027,707	154	616,471	1,312	778,280	0.00 GAS
1,300	3,380	3,549	298	5.30	293,799,400	154	616,586	1,300	778,424	0.00 GAS
1,288	3,368	3,537	298	5.35	296,571,092	153	616,719	1,288	778,592	0.00 GAS
1,276	3,357	3,524	298	5.40	299,342,785	152	616,870	1,276	778,783	0.00 GAS
1,265	3,345	3,512	298	5.45	302,114,477	152	617,039	1,265	778,997	0.00 GAS
1,254	3,334	3,501	298	5.50	304,886,169	151	617,225	1,254	779,232	0.00 GAS
1,243	3,323	3,489	298	5.55	307,657,862	151	617,428	1,243	779,487	0.00 GAS
1,232	3,313	3,478	298	5.60	310,429,554	150	617,645	1,232	779,762	0.00 GAS
1,222	3,302	3,467	298	5.65	313,201,247	150	617,878	1,222	780,055	0.00 GAS
1,211	3,292	3,456	298	5.70	315,972,939	149	618,125	1,211	780,367	0.00 GAS
1,201	3,282	3,446	298	5.75	318,744,632	149	618,385	1,201	780,696	0.00 GAS
1,192	3,272	3,436	298	5.80	321,516,324	148	618,659	1,192	781,042	0.00 GAS
1,182	3,262	3,426	298	5.85	324,288,017	148	618,946	1,182	781,404	0.00 GAS
1,172	3,253	3,416	298	5.90	327,059,709	147	619,245	1,172	781,781	0.00 GAS
1,163	3,244	3,406	298	5.95	329,831,402	147	619,556	1,163	782,174	0.00 GAS
1,154	3,235	3,396	298	6.00	332,603,094	146	619,878	1,154	782,580	0.00 GAS
1,145	3,226	3,387	298	6.05	335,374,786	146	620,211	1,145	783,001	0.00 GAS
1,136	3,217	3,378	298	6.10	338,146,479	145	620,554	1,136	783,434	0.00 GAS
1,128	3,208	3,369	298	6.15	340,918,171	145	620,908	1,128	783,881	0.00 GAS
1,119	3,200	3,360	298	6.20	343,689,864	144	621,271	1,119	784,339	0.00 GAS
1,111	3,192	3,351	298	6.25	346,461,556	144	621,644	1,111	784,810	0.00 GAS
1,103	3,183	3,343	298	6.30	349,233,249	143	622,026	1,103	785,292	0.00 GAS
1,095	3,175	3,334	298	6.35	352,004,941	143	622,416	1,095	785,785	0.00 GAS
1,087	3,168	3,326	298	6.40	354,776,634	142	622,815	1,087	786,289	0.00 GAS
1,079	3,160	3,318	298	6.45	357,548,326	142	623,222	1,079	786,802	0.00 GAS
1,072	3,152	3,310	298	6.50	360,320,018	142	623,637	1,072	787,326	0.00 GAS
1,064	3,145	3,302	298	6.55	363,091,711	141	624,059	1,064	787,859	0.00 GAS
1,057	3,137	3,294	298	6.60	365,863,403	141	624,489	1,057	788,401	0.00 GAS
1,050	3,130	3,287	298	6.65	368,635,096	140	624,925	1,050	788,953	0.00 GAS
1,043	3,123	3,279	298	6.70	371,406,788	140	625,369	1,043	789,512	0.00 GAS
1,036	3,116	3,272	298	6.75	374,178,481	139	625,818	1,036	790,080	0.00 GAS
1,029	3,109	3,265	298	6.80	376,950,173	139	626,274	1,029	790,656	0.00 GAS
1,022	3,103	3,258	298	6.85	379,721,866	139	626,736	1,022	791,239	0.00 GAS
1,015	3,096	3,251	298	6.90	382,493,558	138	627,204	1,015	791,830	0.00 GAS
1,009	3,089	3,244	298	6.95	385,265,251	138	627,678	1,009	792,427	0.00 GAS
1,002	3,083	3,237	298	7.00	388,036,943	137	628,157	1,002	793,032	0.00 GAS
996	3,077	3,230	298	7.05	390,808,635	137	628,641	996	793,643	0.00 GAS

TABLE B.3

$Pressure_{initial}$ Test for Nitrogen

gamma	1.40		
R (J/kg-K)	296.00	Critical Temp (K)	126.20
p_{needed} (Pa)	55,433,849	**Tank Factor**	**10,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	568.26		
Vol_{LH} (m^3)	1,512.23		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	$State_{final}$ Test
13,993	16,074	16,877	298	1.30	72,064,004	276	11,432,065	13,993	10,279,302	0.00	GAS
11,554	13,635	14,316	298	1.35	74,835,696	274	9,802,443	11,554	8,814,005	0.00	GAS
9,854	11,935	12,532	298	1.40	77,607,389	271	8,670,150	9,854	7,795,888	0.00	GAS
8,602	10,682	11,217	298	1.45	80,379,081	268	7,838,468	8,602	7,048,069	0.00	GAS
7,640	9,721	10,207	298	1.50	83,150,774	265	7,202,322	7,640	6,476,070	0.00	GAS
6,879	8,959	9,407	298	1.55	85,922,466	263	6,700,487	6,879	6,024,838	0.00	GAS
6,260	8,341	8,758	298	1.60	88,694,158	261	6,294,871	6,260	5,660,123	0.00	GAS
5,748	7,829	8,220	298	1.65	91,465,851	258	5,960,536	5,748	5,359,500	0.00	GAS
5,317	7,398	7,767	298	1.70	94,237,543	256	5,680,469	5,317	5,107,674	0.00	GAS
4,949	7,029	7,381	298	1.75	97,009,236	254	5,442,668	4,949	4,893,852	0.00	GAS
4,631	6,711	7,047	298	1.80	99,780,928	252	5,238,423	4,631	4,710,202	0.00	GAS
4,353	6,434	6,755	298	1.85	102,552,621	250	5,061,259	4,353	4,550,903	0.00	GAS
4,109	6,189	6,499	298	1.90	105,324,313	248	4,906,265	4,109	4,411,538	0.00	GAS
3,892	5,973	6,271	298	1.95	108,096,006	246	4,769,646	3,892	4,288,695	0.00	GAS
3,698	5,779	6,068	298	2.00	110,867,698	244	4,648,425	3,698	4,179,697	0.00	GAS
3,524	5,605	5,885	298	2.05	113,639,390	243	4,540,232	3,524	4,082,414	0.00	GAS
3,367	5,447	5,720	298	2.10	116,411,083	241	4,443,161	3,367	3,995,131	0.00	GAS
3,224	5,304	5,569	298	2.15	119,182,775	239	4,355,656	3,224	3,916,449	0.00	GAS
3,093	5,174	5,432	298	2.20	121,954,468	238	4,276,439	3,093	3,845,220	0.00	GAS
2,973	5,054	5,307	298	2.25	124,726,160	236	4,204,448	2,973	3,780,489	0.00	GAS
2,863	4,944	5,191	298	2.30	127,497,853	235	4,138,795	2,863	3,721,456	0.00	GAS
2,762	4,842	5,084	298	2.35	130,269,545	233	4,078,730	2,762	3,667,448	0.00	GAS
2,668	4,748	4,986	298	2.40	133,041,238	232	4,023,618	2,668	3,617,892	0.00	GAS
2,580	4,661	4,894	298	2.45	135,812,930	231	3,972,913	2,580	3,572,300	0.00	GAS
2,499	4,579	4,808	298	2.50	138,584,623	229	3,926,148	2,499	3,530,251	0.00	GAS
2,423	4,503	4,729	298	2.55	141,356,315	228	3,882,918	2,423	3,491,381	0.00	GAS
2,352	4,432	4,654	298	2.60	144,128,007	227	3,842,874	2,352	3,455,374	0.00	GAS
2,285	4,366	4,584	298	2.65	146,899,700	226	3,805,707	2,285	3,421,955	0.00	GAS
2,223	4,303	4,518	298	2.70	149,671,392	224	3,771,149	2,223	3,390,882	0.00	GAS
2,163	4,244	4,456	298	2.75	152,443,085	223	3,738,963	2,163	3,361,941	0.00	GAS
2,108	4,188	4,398	298	2.80	155,214,777	222	3,708,940	2,108	3,334,946	0.00	GAS
2,055	4,136	4,342	298	2.85	157,986,470	221	3,680,894	2,055	3,309,728	0.00	GAS
2,005	4,086	4,290	298	2.90	160,758,162	220	3,654,660	2,005	3,286,139	0.00	GAS
1,958	4,039	4,240	298	2.95	163,529,855	219	3,630,091	1,958	3,264,047	0.00	GAS
1,913	3,994	4,193	298	3.00	166,301,547	218	3,607,053	1,913	3,243,333	0.00	GAS
1,871	3,951	4,149	298	3.05	169,073,239	217	3,585,429	1,871	3,223,889	0.00	GAS
1,830	3,910	4,106	298	3.10	171,844,932	216	3,565,110	1,830	3,205,619	0.00	GAS
1,791	3,872	4,065	298	3.15	174,616,624	215	3,546,002	1,791	3,188,438	0.00	GAS
1,754	3,835	4,027	298	3.20	177,388,317	214	3,528,016	1,754	3,172,265	0.00	GAS
1,719	3,800	3,990	298	3.25	180,160,009	213	3,511,072	1,719	3,157,030	0.00	GAS
1,685	3,766	3,954	298	3.30	182,931,702	212	3,495,099	1,685	3,142,667	0.00	GAS
1,653	3,733	3,920	298	3.35	185,703,394	211	3,480,030	1,653	3,129,118	0.00	GAS
1,622	3,703	3,888	298	3.40	188,475,087	210	3,465,805	1,622	3,116,328	0.00	GAS
1,592	3,673	3,856	298	3.45	191,246,779	209	3,452,370	1,592	3,104,248	0.00	GAS
1,564	3,644	3,827	298	3.50	194,018,472	208	3,439,674	1,564	3,092,832	0.00	GAS
1,536	3,617	3,798	298	3.55	196,790,164	207	3,427,670	1,536	3,082,038	0.00	GAS
1,510	3,591	3,770	298	3.60	199,561,856	207	3,416,316	1,510	3,071,829	0.00	GAS
1,485	3,565	3,743	298	3.65	202,333,549	206	3,405,573	1,485	3,062,169	0.00	GAS
1,460	3,541	3,718	298	3.70	205,105,241	205	3,395,404	1,460	3,053,025	0.00	GAS
1,437	3,517	3,693	298	3.75	207,876,934	204	3,385,775	1,437	3,044,367	0.00	GAS
1,414	3,494	3,669	298	3.80	210,648,626	203	3,376,656	1,414	3,036,168	0.00	GAS
1,392	3,473	3,646	298	3.85	213,420,319	203	3,368,018	1,392	3,028,401	0.00	GAS
1,371	3,451	3,624	298	3.90	216,192,011	202	3,359,833	1,371	3,021,041	0.00	GAS

TABLE B.3

1,350	3,431	3,602	298	3.95	218,963,704	201	3,352,078	1,350	3,014,068	0.00	GAS
1,331	3,411	3,582	298	4.00	221,735,396	201	3,344,729	1,331	3,007,460	0.00	GAS
1,311	3,392	3,561	298	4.05	224,507,088	200	3,337,764	1,311	3,001,197	0.00	GAS
1,293	3,373	3,542	298	4.10	227,278,781	199	3,331,163	1,293	2,995,262	0.00	GAS
1,275	3,355	3,523	298	4.15	230,050,473	198	3,324,908	1,275	2,989,638	0.00	GAS
1,257	3,338	3,505	298	4.20	232,822,166	198	3,318,981	1,257	2,984,309	0.00	GAS
1,241	3,321	3,487	298	4.25	235,593,858	197	3,313,366	1,241	2,979,259	0.00	GAS
1,224	3,305	3,470	298	4.30	238,365,551	196	3,308,046	1,224	2,974,476	0.00	GAS
1,208	3,289	3,453	298	4.35	241,137,243	196	3,303,008	1,208	2,969,946	0.00	GAS
1,193	3,273	3,437	298	4.40	243,908,936	195	3,298,238	1,193	2,965,658	0.00	GAS
1,178	3,258	3,421	298	4.45	246,680,628	195	3,293,724	1,178	2,961,598	0.00	GAS
1,163	3,244	3,406	298	4.50	249,452,321	194	3,289,453	1,163	2,957,758	0.00	GAS
1,149	3,229	3,391	298	4.55	252,224,013	193	3,285,414	1,149	2,954,126	0.00	GAS
1,135	3,216	3,376	298	4.60	254,995,705	193	3,281,596	1,135	2,950,694	0.00	GAS
1,122	3,202	3,362	298	4.65	257,767,398	192	3,277,990	1,122	2,947,451	0.00	GAS
1,109	3,189	3,349	298	4.70	260,539,090	192	3,274,586	1,109	2,944,390	0.00	GAS
1,096	3,176	3,335	298	4.75	263,310,783	191	3,271,374	1,096	2,941,503	0.00	GAS
1,083	3,164	3,322	298	4.80	266,082,475	190	3,268,348	1,083	2,938,781	0.00	GAS
1,071	3,152	3,309	298	4.85	268,854,168	190	3,265,498	1,071	2,936,218	0.00	GAS
1,060	3,140	3,297	298	4.90	271,625,860	189	3,262,816	1,060	2,933,807	0.00	GAS
1,048	3,129	3,285	298	4.95	274,397,553	189	3,260,297	1,048	2,931,542	0.00	GAS
1,037	3,117	3,273	298	5.00	277,169,245	188	3,257,933	1,037	2,929,416	0.00	GAS
1,026	3,106	3,262	298	5.05	279,940,937	188	3,255,717	1,026	2,927,424	0.00	GAS
1,015	3,096	3,250	298	5.10	282,712,630	187	3,253,644	1,015	2,925,560	0.00	GAS
1,005	3,085	3,239	298	5.15	285,484,322	187	3,251,708	1,005	2,923,819	0.00	GAS
994	3,075	3,229	298	5.20	288,256,015	186	3,249,903	994	2,922,196	0.00	GAS
985	3,065	3,218	298	5.25	291,027,707	186	3,248,224	985	2,920,686	0.00	GAS
975	3,055	3,208	298	5.30	293,799,400	185	3,246,666	975	2,919,285	0.00	GAS
965	3,046	3,198	298	5.35	296,571,092	185	3,245,224	965	2,917,989	0.00	GAS
956	3,036	3,188	298	5.40	299,342,785	184	3,243,894	956	2,916,793	0.00	GAS
947	3,027	3,179	298	5.45	302,114,477	184	3,242,672	947	2,915,694	0.00	GAS
938	3,018	3,169	298	5.50	304,886,169	183	3,241,553	938	2,914,688	0.00	GAS
929	3,010	3,160	298	5.55	307,657,862	183	3,240,533	929	2,913,771	0.00	GAS
921	3,001	3,151	298	5.60	310,429,554	182	3,239,609	921	2,912,940	0.00	GAS
912	2,993	3,142	298	5.65	313,201,247	182	3,238,777	912	2,912,192	0.00	GAS
904	2,984	3,134	298	5.70	315,972,939	181	3,238,034	904	2,911,524	0.00	GAS
896	2,976	3,125	298	5.75	318,744,632	181	3,237,377	896	2,910,933	0.00	GAS
888	2,969	3,117	298	5.80	321,516,324	180	3,236,802	888	2,910,416	0.00	GAS
880	2,961	3,109	298	5.85	324,288,017	180	3,236,306	880	2,909,971	0.00	GAS
873	2,953	3,101	298	5.90	327,059,709	179	3,235,888	873	2,909,594	0.00	GAS
865	2,946	3,093	298	5.95	329,831,402	179	3,235,543	865	2,909,284	0.00	GAS
858	2,938	3,085	298	6.00	332,603,094	179	3,235,269	858	2,909,038	0.00	GAS
851	2,931	3,078	298	6.05	335,374,786	178	3,235,064	851	2,908,853	0.00	GAS
844	2,924	3,071	298	6.10	338,146,479	178	3,234,925	844	2,908,729	0.00	GAS
837	2,917	3,063	298	6.15	340,918,171	177	3,234,851	837	2,908,662	0.00	GAS
830	2,911	3,056	298	6.20	343,689,864	177	3,234,838	830	2,908,650	0.00	GAS
824	2,904	3,049	298	6.25	346,461,556	177	3,234,885	824	2,908,693	0.00	GAS
817	2,898	3,042	298	6.30	349,233,249	176	3,234,990	817	2,908,787	0.00	GAS
811	2,891	3,036	298	6.35	352,004,941	176	3,235,151	811	2,908,932	0.00	GAS
804	2,885	3,029	298	6.40	354,776,634	175	3,235,366	804	2,909,125	0.00	GAS
798	2,879	3,023	298	6.45	357,548,326	175	3,235,633	798	2,909,365	0.00	GAS
792	2,873	3,016	298	6.50	360,320,018	175	3,235,950	792	2,909,650	0.00	GAS
786	2,867	3,010	298	6.55	363,091,711	174	3,236,316	786	2,909,980	0.00	GAS
780	2,861	3,004	298	6.60	365,863,403	174	3,236,730	780	2,910,351	0.00	GAS
775	2,855	2,998	298	6.65	368,635,096	173	3,237,189	775	2,910,764	0.00	GAS
769	2,849	2,992	298	6.70	371,406,788	173	3,237,692	769	2,911,216	0.00	GAS
763	2,844	2,986	298	6.75	374,178,481	173	3,238,238	763	2,911,707	0.00	GAS
758	2,838	2,980	298	6.80	376,950,173	172	3,238,825	758	2,912,235	0.00	GAS
753	2,833	2,975	298	6.85	379,721,866	172	3,239,452	753	2,912,799	0.00	GAS
747	2,828	2,969	298	6.90	382,493,558	172	3,240,118	747	2,913,398	0.00	GAS
742	2,822	2,964	298	6.95	385,265,251	171	3,240,822	742	2,914,031	0.00	GAS
737	2,817	2,958	298	7.00	388,036,943	171	3,241,562	737	2,914,696	0.00	GAS
732	2,812	2,953	298	7.05	390,808,635	171	3,242,337	732	2,915,393	0.00	GAS

TABLE B.4

$Pressure_{initial}$ Test for Nitrogen

gamma	1.40		
R (J/kg-K)	296.00	Critical Temp (K)	126.20
p_{needed} (Pa)	55,433,849	**Tank Factor**	**50,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	568.26		
Vol_{LH} (m^3)	1,512.23		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	$State_{final}$ Test
13,993	16,074	16,877	298	1.30	72,064,004	276	11,432,065	13,993	2,055,860	0.00	GAS
11,554	13,635	14,316	298	1.35	74,835,696	274	9,802,443	11,554	1,762,801	0.00	GAS
9,854	11,935	12,532	298	1.40	77,607,389	271	8,670,150	9,854	1,559,178	0.00	GAS
8,602	10,682	11,217	298	1.45	80,379,081	268	7,838,468	8,602	1,409,614	0.00	GAS
7,640	9,721	10,207	298	1.50	83,150,774	265	7,202,322	7,640	1,295,214	0.00	GAS
6,879	8,959	9,407	298	1.55	85,922,466	263	6,700,487	6,879	1,204,968	0.00	GAS
6,260	8,341	8,758	298	1.60	88,694,158	261	6,294,871	6,260	1,132,025	0.00	GAS
5,748	7,829	8,220	298	1.65	91,465,851	258	5,960,536	5,748	1,071,900	0.00	GAS
5,317	7,398	7,767	298	1.70	94,237,543	256	5,680,469	5,317	1,021,535	0.00	GAS
4,949	7,029	7,381	298	1.75	97,009,236	254	5,442,668	4,949	978,770	0.00	GAS
4,631	6,711	7,047	298	1.80	99,780,928	252	5,238,423	4,631	942,040	0.00	GAS
4,353	6,434	6,755	298	1.85	102,552,621	250	5,061,259	4,353	910,181	0.00	GAS
4,109	6,189	6,499	298	1.90	105,324,313	248	4,906,265	4,109	882,308	0.00	GAS
3,892	5,973	6,271	298	1.95	108,096,006	246	4,769,646	3,892	857,739	0.00	GAS
3,698	5,779	6,068	298	2.00	110,867,698	244	4,648,425	3,698	835,939	0.00	GAS
3,524	5,605	5,885	298	2.05	113,639,390	243	4,540,232	3,524	816,483	0.00	GAS
3,367	5,447	5,720	298	2.10	116,411,083	241	4,443,161	3,367	799,026	0.00	GAS
3,224	5,304	5,569	298	2.15	119,182,775	239	4,355,656	3,224	783,290	0.00	GAS
3,093	5,174	5,432	298	2.20	121,954,468	238	4,276,439	3,093	769,044	0.00	GAS
2,973	5,054	5,307	298	2.25	124,726,160	236	4,204,448	2,973	756,098	0.00	GAS
2,863	4,944	5,191	298	2.30	127,497,853	235	4,138,795	2,863	744,291	0.00	GAS
2,762	4,842	5,084	298	2.35	130,269,545	233	4,078,730	2,762	733,490	0.00	GAS
2,668	4,748	4,986	298	2.40	133,041,238	232	4,023,618	2,668	723,578	0.00	GAS
2,580	4,661	4,894	298	2.45	135,812,930	231	3,972,913	2,580	714,460	0.00	GAS
2,499	4,579	4,808	298	2.50	138,584,623	229	3,926,148	2,499	706,050	0.00	GAS
2,423	4,503	4,729	298	2.55	141,356,315	228	3,882,918	2,423	698,276	0.00	GAS
2,352	4,432	4,654	298	2.60	144,128,007	227	3,842,874	2,352	691,075	0.00	GAS
2,285	4,366	4,584	298	2.65	146,899,700	226	3,805,707	2,285	684,391	0.00	GAS
2,223	4,303	4,518	298	2.70	149,671,392	224	3,771,149	2,223	678,176	0.00	GAS
2,163	4,244	4,456	298	2.75	152,443,085	223	3,738,963	2,163	672,388	0.00	GAS
2,108	4,188	4,398	298	2.80	155,214,777	222	3,708,940	2,108	666,989	0.00	GAS
2,055	4,136	4,342	298	2.85	157,986,470	221	3,680,894	2,055	661,946	0.00	GAS
2,005	4,086	4,290	298	2.90	160,758,162	220	3,654,660	2,005	657,228	0.00	GAS
1,958	4,039	4,240	298	2.95	163,529,855	219	3,630,091	1,958	652,809	0.00	GAS
1,913	3,994	4,193	298	3.00	166,301,547	218	3,607,053	1,913	648,667	0.00	GAS
1,871	3,951	4,149	298	3.05	169,073,239	217	3,585,429	1,871	644,778	0.00	GAS
1,830	3,910	4,106	298	3.10	171,844,932	216	3,565,110	1,830	641,124	0.00	GAS
1,791	3,872	4,065	298	3.15	174,616,624	215	3,546,002	1,791	637,688	0.00	GAS
1,754	3,835	4,027	298	3.20	177,388,317	214	3,528,016	1,754	634,453	0.00	GAS
1,719	3,800	3,990	298	3.25	180,160,009	213	3,511,072	1,719	631,406	0.00	GAS
1,685	3,766	3,954	298	3.30	182,931,702	212	3,495,099	1,685	628,533	0.00	GAS
1,653	3,733	3,920	298	3.35	185,703,394	211	3,480,030	1,653	625,824	0.00	GAS
1,622	3,703	3,888	298	3.40	188,475,087	210	3,465,805	1,622	623,266	0.00	GAS
1,592	3,673	3,856	298	3.45	191,246,779	209	3,452,370	1,592	620,850	0.00	GAS
1,564	3,644	3,827	298	3.50	194,018,472	208	3,439,674	1,564	618,566	0.00	GAS
1,536	3,617	3,798	298	3.55	196,790,164	207	3,427,670	1,536	616,408	0.00	GAS
1,510	3,591	3,770	298	3.60	199,561,856	207	3,416,316	1,510	614,366	0.00	GAS
1,485	3,565	3,743	298	3.65	202,333,549	206	3,405,573	1,485	612,434	0.00	GAS
1,460	3,541	3,718	298	3.70	205,105,241	205	3,395,404	1,460	610,605	0.00	GAS
1,437	3,517	3,693	298	3.75	207,876,934	204	3,385,775	1,437	608,873	0.00	GAS
1,414	3,494	3,669	298	3.80	210,648,626	203	3,376,656	1,414	607,234	0.00	GAS
1,392	3,473	3,646	298	3.85	213,420,319	203	3,368,018	1,392	605,680	0.00	GAS
1,371	3,451	3,624	298	3.90	216,192,011	202	3,359,833	1,371	604,208	0.00	GAS

TABLE B.4

1,350	3,431	3,602	298	3.95	218,963,704	201	3,352,078	1,350	602,814	0.00 GAS
1,331	3,411	3,582	298	4.00	221,735,396	201	3,344,729	1,331	601,492	0.00 GAS
1,311	3,392	3,561	298	4.05	224,507,088	200	3,337,764	1,311	600,239	0.00 GAS
1,293	3,373	3,542	298	4.10	227,278,781	199	3,331,163	1,293	599,052	0.00 GAS
1,275	3,355	3,523	298	4.15	230,050,473	198	3,324,908	1,275	597,928	0.00 GAS
1,257	3,338	3,505	298	4.20	232,822,166	198	3,318,981	1,257	596,862	0.00 GAS
1,241	3,321	3,487	298	4.25	235,593,858	197	3,313,366	1,241	595,852	0.00 GAS
1,224	3,305	3,470	298	4.30	238,365,551	196	3,308,046	1,224	594,895	0.00 GAS
1,208	3,289	3,453	298	4.35	241,137,243	196	3,303,008	1,208	593,989	0.00 GAS
1,193	3,273	3,437	298	4.40	243,908,936	195	3,298,238	1,193	593,132	0.00 GAS
1,178	3,258	3,421	298	4.45	246,680,628	195	3,293,724	1,178	592,320	0.00 GAS
1,163	3,244	3,406	298	4.50	249,452,321	194	3,289,453	1,163	591,552	0.00 GAS
1,149	3,229	3,391	298	4.55	252,224,013	193	3,285,414	1,149	590,825	0.00 GAS
1,135	3,216	3,376	298	4.60	254,995,705	193	3,281,596	1,135	590,139	0.00 GAS
1,122	3,202	3,362	298	4.65	257,767,398	192	3,277,990	1,122	589,490	0.00 GAS
1,109	3,189	3,349	298	4.70	260,539,090	192	3,274,586	1,109	588,878	0.00 GAS
1,096	3,176	3,335	298	4.75	263,310,783	191	3,271,374	1,096	588,301	0.00 GAS
1,083	3,164	3,322	298	4.80	266,082,475	190	3,268,348	1,083	587,756	0.00 GAS
1,071	3,152	3,309	298	4.85	268,854,168	190	3,265,498	1,071	587,244	0.00 GAS
1,060	3,140	3,297	298	4.90	271,625,860	189	3,262,816	1,060	586,761	0.00 GAS
1,048	3,129	3,285	298	4.95	274,397,553	189	3,260,297	1,048	586,308	0.00 GAS
1,037	3,117	3,273	298	5.00	277,169,245	188	3,257,933	1,037	585,883	0.00 GAS
1,026	3,106	3,262	298	5.05	279,940,937	188	3,255,717	1,026	585,485	0.00 GAS
1,015	3,096	3,250	298	5.10	282,712,630	187	3,253,644	1,015	585,112	0.00 GAS
1,005	3,085	3,239	298	5.15	285,484,322	187	3,251,708	1,005	584,764	0.00 GAS
994	3,075	3,229	298	5.20	288,256,015	186	3,249,903	994	584,439	0.00 GAS
985	3,065	3,218	298	5.25	291,027,707	186	3,248,224	985	584,137	0.00 GAS
975	3,055	3,208	298	5.30	293,799,400	185	3,246,666	975	583,857	0.00 GAS
965	3,046	3,198	298	5.35	296,571,092	185	3,245,224	965	583,598	0.00 GAS
956	3,036	3,188	298	5.40	299,342,785	184	3,243,894	956	583,359	0.00 GAS
947	3,027	3,179	298	5.45	302,114,477	184	3,242,672	947	583,139	0.00 GAS
938	3,018	3,169	298	5.50	304,886,169	183	3,241,553	938	582,938	0.00 GAS
929	3,010	3,160	298	5.55	307,657,862	183	3,240,533	929	582,754	0.00 GAS
921	3,001	3,151	298	5.60	310,429,554	182	3,239,609	921	582,588	0.00 GAS
912	2,993	3,142	298	5.65	313,201,247	182	3,238,777	912	582,438	0.00 GAS
904	2,984	3,134	298	5.70	315,972,939	181	3,238,034	904	582,305	0.00 GAS
896	2,976	3,125	298	5.75	318,744,632	181	3,237,377	896	582,187	0.00 GAS
888	2,969	3,117	298	5.80	321,516,324	180	3,236,802	888	582,083	0.00 GAS
880	2,961	3,109	298	5.85	324,288,017	180	3,236,306	880	581,994	0.00 GAS
873	2,953	3,101	298	5.90	327,059,709	179	3,235,888	873	581,919	0.00 GAS
865	2,946	3,093	298	5.95	329,831,402	179	3,235,543	865	581,857	0.00 GAS
858	2,938	3,085	298	6.00	332,603,094	179	3,235,269	858	581,808	0.00 GAS
851	2,931	3,078	298	6.05	335,374,786	178	3,235,064	851	581,771	0.00 GAS
844	2,924	3,071	298	6.10	338,146,479	178	3,234,925	844	581,746	0.00 GAS
837	2,917	3,063	298	6.15	340,918,171	177	3,234,851	837	581,732	0.00 GAS
830	2,911	3,056	298	6.20	343,689,864	177	3,234,838	830	581,730	0.00 GAS
824	2,904	3,049	298	6.25	346,461,556	177	3,234,885	824	581,739	0.00 GAS
817	2,898	3,042	298	6.30	349,233,249	176	3,234,990	817	581,757	0.00 GAS
811	2,891	3,036	298	6.35	352,004,941	176	3,235,151	811	581,786	0.00 GAS
804	2,885	3,029	298	6.40	354,776,634	175	3,235,366	804	581,825	0.00 GAS
798	2,879	3,023	298	6.45	357,548,326	175	3,235,633	798	581,873	0.00 GAS
792	2,873	3,016	298	6.50	360,320,018	175	3,235,950	792	581,930	0.00 GAS
786	2,867	3,010	298	6.55	363,091,711	174	3,236,316	786	581,996	0.00 GAS
780	2,861	3,004	298	6.60	365,863,403	174	3,236,730	780	582,070	0.00 GAS
775	2,855	2,998	298	6.65	368,635,096	173	3,237,189	775	582,153	0.00 GAS
769	2,849	2,992	298	6.70	371,406,788	173	3,237,692	769	582,243	0.00 GAS
763	2,844	2,986	298	6.75	374,178,481	173	3,238,238	763	582,341	0.00 GAS
758	2,838	2,980	298	6.80	376,950,173	172	3,238,825	758	582,447	0.00 GAS
753	2,833	2,975	298	6.85	379,721,866	172	3,239,452	753	582,560	0.00 GAS
747	2,828	2,969	298	6.90	382,493,558	172	3,240,118	747	582,680	0.00 GAS
742	2,822	2,964	298	6.95	385,265,251	171	3,240,822	742	582,806	0.00 GAS
737	2,817	2,958	298	7.00	388,036,943	171	3,241,562	737	582,939	0.00 GAS
732	2,812	2,953	298	7.05	390,808,635	171	3,242,337	732	583,079	0.00 GAS

TABLE B.5

$\text{Pressure}_{\text{initial}}$ Test for Argon

gamma	1.67		
R (J/kg-K)	208.00	Critical Temp (K)	150.80
p_{needed} (Pa)	55,433,849	**Tank Factor**	**10,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	568.26		
Vol_{LH} (m^3)	1,512.23		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	State_{final} Test
18,186	20,267	21,280	298	1.30	72,064,004	268	21,143,941	18,186	13,359,694	0.00	GAS
14,875	16,955	17,803	298	1.35	74,835,696	264	17,958,629	14,875	11,347,071	0.00	GAS
12,612	14,692	15,427	298	1.40	77,607,389	260	15,790,616	12,612	9,977,223	0.00	GAS
10,967	13,048	13,700	298	1.45	80,379,081	257	14,221,849	10,967	8,986,005	0.00	GAS
9,717	11,798	12,388	298	1.50	83,150,774	253	13,035,698	9,717	8,236,541	0.00	GAS
8,735	10,816	11,356	298	1.55	85,922,466	250	12,108,690	8,735	7,650,816	0.00	GAS
7,943	10,023	10,524	298	1.60	88,694,158	247	11,365,296	7,943	7,181,106	0.00	GAS
7,290	9,370	9,839	298	1.65	91,465,851	244	10,756,720	7,290	6,796,581	0.00	GAS
6,742	8,822	9,263	298	1.70	94,237,543	241	10,250,036	6,742	6,476,435	0.00	GAS
6,276	8,356	8,774	298	1.75	97,009,236	238	9,822,219	6,276	6,206,121	0.00	GAS
5,875	7,955	8,353	298	1.80	99,780,928	235	9,456,687	5,875	5,975,161	0.00	GAS
5,525	7,606	7,986	298	1.85	102,552,621	233	9,141,193	5,525	5,775,818	0.00	GAS
5,218	7,298	7,663	298	1.90	105,324,313	230	8,866,497	5,218	5,602,252	0.00	GAS
4,946	7,026	7,378	298	1.95	108,096,006	228	8,625,496	4,946	5,449,977	0.00	GAS
4,703	6,784	7,123	298	2.00	110,867,698	226	8,412,641	4,703	5,315,486	0.00	GAS
4,485	6,566	6,894	298	2.05	113,639,390	223	8,223,533	4,485	5,195,999	0.00	GAS
4,289	6,369	6,688	298	2.10	116,411,083	221	8,054,642	4,289	5,089,286	0.00	GAS
4,110	6,191	6,500	298	2.15	119,182,775	219	7,903,100	4,110	4,993,534	0.00	GAS
3,947	6,028	6,329	298	2.20	121,954,468	217	7,766,554	3,947	4,907,259	0.00	GAS
3,798	5,879	6,173	298	2.25	124,726,160	215	7,643,058	3,798	4,829,229	0.00	GAS
3,661	5,742	6,029	298	2.30	127,497,853	213	7,530,984	3,661	4,758,415	0.00	GAS
3,535	5,615	5,896	298	2.35	130,269,545	212	7,428,964	3,535	4,693,954	0.00	GAS
3,418	5,498	5,773	298	2.40	133,041,238	210	7,335,837	3,418	4,635,112	0.00	GAS
3,309	5,390	5,659	298	2.45	135,812,930	208	7,250,612	3,309	4,581,264	0.00	GAS
3,208	5,288	5,553	298	2.50	138,584,623	206	7,172,441	3,208	4,531,872	0.00	GAS
3,114	5,194	5,454	298	2.55	141,356,315	205	7,100,591	3,114	4,486,473	0.00	GAS
3,025	5,106	5,361	298	2.60	144,128,007	203	7,034,424	3,025	4,444,666	0.00	GAS
2,942	5,023	5,274	298	2.65	146,899,700	202	6,973,387	2,942	4,406,100	0.00	GAS
2,865	4,945	5,192	298	2.70	149,671,392	200	6,916,993	2,865	4,370,468	0.00	GAS
2,791	4,872	5,115	298	2.75	152,443,085	199	6,864,816	2,791	4,337,500	0.00	GAS
2,722	4,803	5,043	298	2.80	155,214,777	197	6,816,479	2,722	4,306,959	0.00	GAS
2,657	4,737	4,974	298	2.85	157,986,470	196	6,771,648	2,657	4,278,632	0.00	GAS
2,595	4,675	4,909	298	2.90	160,758,162	194	6,730,025	2,595	4,252,333	0.00	GAS
2,536	4,617	4,848	298	2.95	163,529,855	193	6,691,345	2,536	4,227,893	0.00	GAS
2,481	4,561	4,789	298	3.00	166,301,547	192	6,655,372	2,481	4,205,164	0.00	GAS
2,428	4,508	4,734	298	3.05	169,073,239	191	6,621,893	2,428	4,184,010	0.00	GAS
2,377	4,458	4,681	298	3.10	171,844,932	189	6,590,715	2,377	4,164,311	0.00	GAS
2,329	4,410	4,630	298	3.15	174,616,624	188	6,561,667	2,329	4,145,957	0.00	GAS
2,283	4,364	4,582	298	3.20	177,388,317	187	6,534,591	2,283	4,128,849	0.00	GAS
2,240	4,320	4,536	298	3.25	180,160,009	186	6,509,347	2,240	4,112,899	0.00	GAS
2,198	4,278	4,492	298	3.30	182,931,702	185	6,485,804	2,198	4,098,023	0.00	GAS
2,157	4,238	4,450	298	3.35	185,703,394	183	6,463,846	2,157	4,084,149	0.00	GAS
2,119	4,200	4,409	298	3.40	188,475,087	182	6,443,365	2,119	4,071,208	0.00	GAS
2,082	4,163	4,371	298	3.45	191,246,779	181	6,424,264	2,082	4,059,139	0.00	GAS
2,047	4,127	4,334	298	3.50	194,018,472	180	6,406,452	2,047	4,047,885	0.00	GAS
2,013	4,093	4,298	298	3.55	196,790,164	179	6,389,847	2,013	4,037,393	0.00	GAS
1,980	4,060	4,263	298	3.60	199,561,856	178	6,374,374	1,980	4,027,617	0.00	GAS
1,948	4,029	4,230	298	3.65	202,333,549	177	6,359,963	1,948	4,018,511	0.00	GAS
1,918	3,998	4,198	298	3.70	205,105,241	176	6,346,549	1,918	4,010,036	0.00	GAS
1,889	3,969	4,168	298	3.75	207,876,934	175	6,334,073	1,889	4,002,152	0.00	GAS
1,860	3,941	4,138	298	3.80	210,648,626	174	6,322,479	1,860	3,994,827	0.00	GAS
1,833	3,914	4,109	298	3.85	213,420,319	174	6,311,718	1,833	3,988,028	0.00	GAS
1,807	3,887	4,082	298	3.90	216,192,011	173	6,301,740	1,807	3,981,724	0.00	GAS

TABLE B.5

1,781	3,862	4,055	298	3.95	218,963,704	172	6,292,504	1,781	3,975,888	0.00	GAS
1,757	3,837	4,029	298	4.00	221,735,396	171	6,283,967	1,757	3,970,494	0.00	GAS
1,733	3,813	4,004	298	4.05	224,507,088	170	6,276,092	1,733	3,965,518	0.00	GAS
1,710	3,790	3,980	298	4.10	227,278,781	169	6,268,843	1,710	3,960,937	0.00	GAS
1,687	3,768	3,956	298	4.15	230,050,473	168	6,262,187	1,687	3,956,732	0.00	GAS
1,666	3,746	3,933	298	4.20	232,822,166	168	6,256,093	1,666	3,952,882	0.00	GAS
1,644	3,725	3,911	298	4.25	235,593,858	167	6,250,533	1,644	3,949,368	0.00	GAS
1,624	3,705	3,890	298	4.30	238,365,551	166	6,245,478	1,624	3,946,174	0.00	GAS
1,604	3,685	3,869	298	4.35	241,137,243	165	6,240,904	1,604	3,943,284	0.00	GAS
1,585	3,665	3,849	298	4.40	243,908,936	164	6,236,787	1,585	3,940,683	0.00	GAS
1,566	3,647	3,829	298	4.45	246,680,628	164	6,233,104	1,566	3,938,356	0.00	GAS
1,548	3,628	3,810	298	4.50	249,452,321	163	6,229,835	1,548	3,936,290	0.00	GAS
1,530	3,611	3,791	298	4.55	252,224,013	162	6,226,959	1,530	3,934,473	0.00	GAS
1,513	3,594	3,773	298	4.60	254,995,705	162	6,224,458	1,513	3,932,893	0.00	GAS
1,496	3,577	3,756	298	4.65	257,767,398	161	6,222,314	1,496	3,931,539	0.00	GAS
1,480	3,560	3,738	298	4.70	260,539,090	160	6,220,512	1,480	3,930,400	0.00	GAS
1,464	3,544	3,722	298	4.75	263,310,783	159	6,219,034	1,464	3,929,466	0.00	GAS
1,448	3,529	3,705	298	4.80	266,082,475	159	6,217,867	1,448	3,928,729	0.00	GAS
1,433	3,514	3,689	298	4.85	268,854,168	158	6,216,997	1,433	3,928,179	0.00	GAS
1,419	3,499	3,674	298	4.90	271,625,860	158	6,216,409	1,419	3,927,808	0.00	GAS
1,404	3,485	3,659	298	4.95	274,397,553	157	6,216,093	1,404	3,927,608	0.00	GAS
1,390	3,471	[illegible]	298	5.00	277,169,245	156	6,216,036	1,390	3,927,571	0.00	GAS
1,376	3,457	3,630	298	5.05	279,940,937	156	6,216,226	1,376	3,927,692	0.00	GAS
1,363	3,443	3,616	298	5.10	282,712,630	155	6,216,654	1,363	3,927,962	0.00	GAS
1,350	3,430	3,602	298	5.15	285,484,322	154	6,217,308	1,350	3,928,376	0.00	GAS
1,337	3,418	3,588	298	5.20	288,256,015	154	6,218,180	1,337	3,928,927	0.00	GAS
1,325	3,405	3,575	298	5.25	291,027,707	153	6,219,261	1,325	3,929,609	0.00	GAS
1,312	3,393	3,563	298	5.30	293,799,400	153	6,220,541	1,312	3,930,418	0.00	GAS
1,300	3,381	3,550	298	5.35	296,571,092	152	6,222,013	1,300	3,931,348	0.00	GAS
1,289	3,369	3,538	298	5.40	299,342,785	151	6,223,669	1,289	3,932,395	0.00	GAS
1,277	3,358	3,526	298	5.45	302,114,477	151	6,225,501	1,277	3,933,552	0.00	GAS
1,266	3,347	3,514	298	5.50	304,886,169	150	6,227,502	1,266	3,934,816	0.00	possible liq
1,255	3,336	3,502	298	5.55	307,657,862	150	6,229,666	1,255	3,936,183	0.00	possible liq
1,244	3,325	3,491	298	5.60	310,429,554	149	6,231,985	1,244	3,937,649	0.00	possible liq
1,234	3,314	3,480	298	5.65	313,201,247	149	6,234,455	1,234	3,939,209	0.00	possible liq
1,224	3,304	3,469	298	5.70	315,972,939	148	6,237,068	1,224	3,940,860	0.00	possible liq
1,213	3,294	3,459	298	5.75	318,744,632	148	6,239,819	1,213	3,942,599	0.00	possible liq
1,204	3,284	3,448	298	5.80	321,516,324	147	6,242,704	1,204	3,944,422	0.00	possible liq
1,194	3,274	3,438	298	5.85	324,288,017	147	6,245,717	1,194	3,946,325	0.00	possible liq
1,184	3,265	3,428	298	5.90	327,059,709	146	6,248,852	1,184	3,948,306	0.00	possible liq
1,175	3,255	3,418	298	5.95	329,831,402	146	6,252,106	1,175	3,950,362	0.00	possible liq
1,166	3,246	3,409	298	6.00	332,603,094	145	6,255,474	1,166	3,952,490	0.00	possible liq
1,157	3,237	3,399	298	6.05	335,374,786	145	6,258,951	1,157	3,954,687	0.00	possible liq
1,148	3,228	3,390	298	6.10	338,146,479	144	6,262,534	1,148	3,956,951	0.00	possible liq
1,139	3,220	3,381	298	6.15	340,918,171	144	6,266,218	1,139	3,959,279	0.00	possible liq
1,131	3,211	3,372	298	6.20	343,689,864	143	6,270,000	1,131	3,961,668	0.00	possible liq
1,122	3,203	3,363	298	6.25	346,461,556	143	6,273,876	1,122	3,964,117	0.00	possible liq
1,114	3,195	3,354	298	6.30	349,233,249	142	6,277,843	1,114	3,966,624	0.00	possible liq
1,106	3,187	3,346	298	6.35	352,004,941	142	6,281,897	1,106	3,969,185	0.00	possible liq
1,098	3,179	3,338	298	6.40	354,776,634	142	6,286,035	1,098	3,971,800	0.00	possible liq
1,090	3,171	3,330	298	6.45	357,548,326	141	6,290,254	1,090	3,974,466	0.00	possible liq
1,083	3,163	3,321	298	6.50	360,320,018	141	6,294,552	1,083	3,977,181	0.00	possible liq
1,075	3,156	3,314	298	6.55	363,091,711	140	6,298,924	1,075	3,979,944	0.00	possible liq
1,068	3,148	3,306	298	6.60	365,863,403	140	6,303,370	1,068	3,982,753	0.00	possible liq
1,061	3,141	3,298	298	6.65	368,635,096	139	6,307,885	1,061	3,985,606	0.00	possible liq
1,053	3,134	3,291	298	6.70	371,406,788	139	6,312,468	1,053	3,988,502	0.00	possible liq
1,046	3,127	3,283	298	6.75	374,178,481	139	6,317,116	1,046	3,991,439	0.00	possible liq
1,040	3,120	3,276	298	6.80	376,950,173	138	6,321,827	1,040	3,994,415	0.00	possible liq
1,033	3,113	3,269	298	6.85	379,721,866	138	6,326,598	1,033	3,997,430	0.00	possible liq
1,026	3,107	3,262	298	6.90	382,493,558	137	6,331,428	1,026	4,000,481	0.00	possible liq
1,019	3,100	3,255	298	6.95	385,265,251	137	6,336,314	1,019	4,003,569	0.00	possible liq
1,013	3,093	3,248	298	7.00	388,036,943	137	6,341,254	1,013	4,006,690	0.00	possible liq
1,007	3,087	3,241	298	7.05	390,808,635	136	6,346,247	1,007	4,009,845	0.00	possible liq

TABLE B.7

ΔV & T/W Calculations For Helium Pressurant, Sit. 1			
Stage 1		**Stage 2**	
SSME's		**SSME's**	
$mdot_{tot\text{-}SSME\text{-}1}$ (kg/s) (90%)	1,264.64	$mdot_{tot\text{-}SSME\text{-}1}$ (kg/s) (104%)	1,461.36
$mdot_{tot\text{-}SSME\text{-}2}$ (kg/s) (100%)	1,405.15	$t_{burn\ stage\text{-}2}$(s) preburn	388.00
$mdot_{tot\text{-}SSME\text{-}3}$ (kg/s) (70%)	983.61	$m_{prop\text{-}SSME\text{-}stg2}$ (kg)	567,008.08
$mdot_{tot\text{-}SSME\text{-}4}$ (kg/s) (104%)	1,461.36	$m_{prop\text{-}LH\text{-}SSME\text{-}stg2}$ (kg)	81,001.15
$t_{burn\ stg1\text{-}1}$(s) preburn	6.60	$m_{prop\text{-}OX\text{-}SSME\text{-}stg2}$ (kg)	486,006.92
$t_{burn\ stg1\text{-}2}$(s) liftoff	30.00		
$t_{burn\ stg1\text{-}3}$(s) throttle back	31.00		
$t_{burn\ stg1\text{-}4}$(s) throttle back	65.00		
$m_{prop\text{-}SSME\text{-}stg1}$ (kg)	175,981.59		
$m_{prop\text{-}LH\text{-}SSME\text{-}stg1}$ (kg)	25,140.23		
$m_{prop\text{-}OX\text{-}SSME\text{-}stg1}$ (kg)	150,841.36		
ET		**ET**	
$m_{tank\text{-}LH}$ (kg)	1,148,202.75	$m_{tank\text{-}LH}$ (kg)	1,148,202.75
$m_{tank\text{-}OX}$ (kg)	505,679.88	$m_{tank\text{-}OX}$ (kg)	505,679.88
$m_{tank\text{-}press}$ (kg)	3,889,790.17	$m_{tank\text{-}press}$ (kg)	3,889,790.17
m_{press} (kg)	616,216.57	m_{press} (kg)	616,216.57
$m_{LH\text{-}tot}$ (kg)	102,000.00	$m_{LH\text{-}tot}$ (kg)	76,859.77
$m_{OX\text{-}tot}$ (kg)	616,500.00	$m_{OX\text{-}tot}$ (kg)	465,658.64
$m_{inter\text{-}tank}$ (kg)	5,487.00	$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00	$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00	$m_{external\text{-}HW}$ (kg)	4,126.00
SRM's			
$m_{booster\ tot\ inert}$ (kg)	174,120.00		
$m_{booster\ tot\ wet}$ (kg)	1,171,682.00		
$m_{SRM\text{-}prop\text{-}tot}$ (kg)	997,562.00		
ΔV calculation		**ΔV calculation**	
$Isp_{stage\text{-}1}$ (s)	269.30	$Isp_{stage\text{-}2}$ (s)	455.00
$m_{prop\text{-}tot}$ (kg)	1,173,543.59	$m_{prop\text{-}tot}$ (kg)	567,008.08
$m_{inert\text{-}tot}$ (kg)	6,888,327.78	$m_{inert\text{-}tot}$ (kg)	6,171,689.37
$m_{orb\ w/P/L}$ (kg)	104,500.00	$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	409.8513041	ΔV (m/s)	386.0617119
		ΔV_{tot} (m/s)	**795.9130161**
F/W Calculation		**F/W Calculation**	
$m_{tot\text{-}initial}$ (kg)	8,166,371.37	$m_{tot\text{-}initial}$ (kg)	6,843,197.45
$Thrust_{tot\text{-}SSME's}$ (N)	6,522,858.00	$Thrust_{tot\text{-}SSME's}$ (N)	6,522,858.00
$Thrust_{tot\text{-}SRM's}$ (N)	23,600,000.00		
F/W	**0.376008828**	**F/W**	**0.097164998**

TABLE B.8

ΔV & T/W Calculations For Helium Pressurant, Sit. 2			
Stage 1		**Stage 2**	
SSME's		**SSME's**	
mdot$_{tot-SSME-1}$ (kg/s) (90%)	1,264.64	mdot$_{tot-SSME-1}$ (kg/s) (104%)	1,461.36
mdot$_{tot-SSME-2}$ (kg/s) (100%)	1,405.15	$t_{burn\ stage-2}$(s) preburn	388.00
mdot$_{tot-SSME-3}$ (kg/s) (70%)	983.61	$m_{prop-SSME-stg2}$ (kg)	567,008.08
mdot$_{tot-SSME-4}$ (kg/s) (104%)	1,461.36	$m_{prop-LH-SSME-stg2}$ (kg)	81,001.15
$t_{burn\ stg1-1}$(s) preburn	6.60	$m_{prop-OX-SSME-stg2}$ (kg)	486,006.92
$t_{burn\ stg1-2}$(s) liftoff	30.00		
$t_{burn\ stg1-3}$(s) throttle back	31.00		
$t_{burn\ stg1-4}$(s) throttle back	65.00		
$m_{prop-SSME-stg1}$ (kg)	175,981.59		
$m_{prop-LH-SSME-stg1}$ (kg)	25,140.23		
$m_{prop-OX-SSME-stg1}$ (kg)	150,841.36		
ET		**ET**	
$m_{tank-LH}$ (kg)	1,148,202.75	$m_{tank-LH}$ (kg)	1,148,202.75
$m_{tank-OX}$ (kg)	505,679.88	$m_{tank-OX}$ (kg)	505,679.88
$m_{tank-press}$ (kg)	777,958.03	$m_{tank-press}$ (kg)	777,958.03
m_{press} (kg)	616,216.57	m_{press} (kg)	616,216.57
m_{LH-tot} (kg)	102,000.00	m_{LH-tot} (kg)	76,859.77
m_{OX-tot} (kg)	616,500.00	m_{OX-tot} (kg)	465,658.64
$m_{inter-tank}$ (kg)	5,487.00	$m_{inter-tank}$ (kg)	5,487.00
$m_{thermal-prot}$ (kg)	2,187.00	$m_{thermal-prot}$ (kg)	2,187.00
$m_{external-HW}$ (kg)	4,126.00	$m_{external-HW}$ (kg)	4,126.00
SRM's			
$m_{booster\ tot\ inert}$ (kg)	174,120.00		
$m_{booster\ tot\ wet}$ (kg)	1,171,682.00		
$m_{SRM-prop-tot}$ (kg)	997,562.00		
ΔV calculation		**ΔV calculation**	
$Isp_{stage-1}$ (s)	269.30	$Isp_{stage-2}$ (s)	455.00
$m_{prop-tot}$ (kg)	1,173,543.59	$m_{prop-tot}$ (kg)	567,008.08
$m_{inert-tot}$ (kg)	3,776,495.65	$m_{inert-tot}$ (kg)	3,059,857.24
$m_{orb\ w/P/L}$ (kg)	104,500.00	$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	697.9560226	ΔV (m/s)	735.7012918
		ΔV_{tot} (m/s)	**1433.657314**
F/W Calculation		**F/W Calculation**	
$m_{tot-initial}$ (kg)	5,054,539.24	$m_{tot-initial}$ (kg)	3,731,365.31
$Thrust_{tot-SSME's}$ (N)	6,522,858.00	$Thrust_{tot-SSME's}$ (N)	6,522,858.00
$Thrust_{tot-SRM's}$ (N)	23,600,000.00		
F/W	**0.607499038**	**F/W**	**0.178197311**

TABLE B.9

ΔV & T/W Calculations
For Nitrogen Pressurant, Sit. 1

Stage 1		Stage 2	
SSME's		**SSME's**	
mdot$_{\text{tot-SSME-1}}$ (kg/s) (90%)	1,264.64	mdot$_{\text{tot-SSME-1}}$ (kg/s) (104%)	1,461.36
mdot$_{\text{tot-SSME-2}}$ (kg/s) (100%)	1,405.15	$t_{\text{burn stage-2}}$(s) preburn	388.00
mdot$_{\text{tot-SSME-3}}$ (kg/s) (70%)	983.61	$m_{\text{prop-SSME-stg2}}$ (kg)	567,008.08
mdot$_{\text{tot-SSME-4}}$ (kg/s) (104%)	1,461.36	$m_{\text{prop-LH-SSME-stg2}}$ (kg)	81,001.15
$t_{\text{burn stg1-1}}$(s) preburn	6.60	$m_{\text{prop-OX-SSME-stg2}}$ (kg)	486,006.92
$t_{\text{burn stg1-2}}$(s) liftoff	30.00		
$t_{\text{burn stg1-3}}$(s) throttle back	31.00		
$t_{\text{burn stg1-4}}$(s) throttle back	65.00		
$m_{\text{prop-SSME-stg1}}$ (kg)	175,981.59		
$m_{\text{prop-LH-SSME-stg1}}$ (kg)	25,140.23		
$m_{\text{prop-OX-SSME-stg1}}$ (kg)	150,841.36		
ET		**ET**	
$m_{\text{tank-LH}}$ (kg)	1,148,202.75	$m_{\text{tank-LH}}$ (kg)	1,148,202.75
$m_{\text{tank-OX}}$ (kg)	505,679.88	$m_{\text{tank-OX}}$ (kg)	505,679.88
$m_{\text{tank-press}}$ (kg)	2,908,650.46	$m_{\text{tank-press}}$ (kg)	2,908,650.46
m_{press} (kg)	3,234,838.23	m_{press} (kg)	3,234,838.23
$m_{\text{LH-tot}}$ (kg)	102,000.00	$m_{\text{LH-tot}}$ (kg)	76,859.77
$m_{\text{OX-tot}}$ (kg)	616,500.00	$m_{\text{OX-tot}}$ (kg)	465,658.64
$m_{\text{inter-tank}}$ (kg)	5,487.00	$m_{\text{inter-tank}}$ (kg)	5,487.00
$m_{\text{thermal-prot}}$ (kg)	2,187.00	$m_{\text{thermal-prot}}$ (kg)	2,187.00
$m_{\text{external-HW}}$ (kg)	4,126.00	$m_{\text{external-HW}}$ (kg)	4,126.00
SRM's			
$m_{\text{booster tot inert}}$ (kg)	174,120.00		
$m_{\text{booster tot wet}}$ (kg)	1,171,682.00		
$m_{\text{SRM-prop-tot}}$ (kg)	997,562.00		
ΔV calculation		**ΔV calculation**	
$Isp_{\text{stage-1}}$ (s)	269.30	$Isp_{\text{stage-2}}$ (s)	455.00
$m_{\text{prop-tot}}$ (kg)	1,173,543.59	$m_{\text{prop-tot}}$ (kg)	567,008.08
$m_{\text{inert-tot}}$ (kg)	8,525,809.73	$m_{\text{inert-tot}}$ (kg)	7,809,171.32
$m_{\text{orb w/P/L}}$ (kg)	104,500.00	$m_{\text{orb w/P/L}}$ (kg)	104,500.00
ΔV (m/s)	336.8193598	ΔV (m/s)	308.8720965
		ΔV_{tot} (m/s)	**645.6914563**
F/W Calculation		**F/W Calculation**	
$m_{\text{tot-initial}}$ (kg)	9,803,853.32	$m_{\text{tot-initial}}$ (kg)	8,480,679.40
$Thrust_{\text{tot-SSME's}}$ (N)	6,522,858.00	$Thrust_{\text{tot-SSME's}}$ (N)	6,522,858.00
$Thrust_{\text{tot-SRM's}}$ (N)	23,600,000.00		
F/W	**0.313206208**	**F/W**	**0.078404009**

TABLE B.10

ΔV & T/W Calculations
For Nitrogen Pressurant, Sit. 2

Stage 1

SSME's	
$mdot_{tot\text{-}SSME\text{-}1}$ (kg/s) (90%)	1,264.64
$mdot_{tot\text{-}SSME\text{-}2}$ (kg/s) (100%)	1,405.15
$mdot_{tot\text{-}SSME\text{-}3}$ (kg/s) (70%)	983.61
$mdot_{tot\text{-}SSME\text{-}4}$ (kg/s) (104%)	1,461.36
$t_{burn\ stg1\text{-}1}$(s) preburn	6.60
$t_{burn\ stg1\text{-}2}$(s) liftoff	30.00
$t_{burn\ stg1\text{-}3}$(s) throttle back	31.00
$t_{burn\ stg1\text{-}4}$(s) throttle back	65.00
$m_{prop\text{-}SSME\text{-}stg1}$ (kg)	175,981.59
$m_{prop\text{-}LH\text{-}SSME\text{-}stg1}$ (kg)	25,140.23
$m_{prop\text{-}OX\text{-}SSME\text{-}stg1}$ (kg)	150,841.36
ET	
$m_{tank\text{-}LH}$ (kg)	1,148,202.75
$m_{tank\text{-}OX}$ (kg)	505,679.88
$m_{tank\text{-}press}$ (kg)	581,730.09
m_{press} (kg)	3,234,838.23
$m_{LH\text{-}tot}$ (kg)	102,000.00
$m_{OX\text{-}tot}$ (kg)	616,500.00
$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00
SRM's	
$m_{booster\ tot\ inert}$ (kg)	174,120.00
$m_{booster\ tot\ wet}$ (kg)	1,171,682.00
$m_{SRM\text{-}prop\text{-}tot}$ (kg)	997,562.00
ΔV calculation	
$Isp_{stage\text{-}1}$ (s)	269.30
$m_{prop\text{-}tot}$ (kg)	1,173,543.59
$m_{inert\text{-}tot}$ (kg)	6,198,889.36
$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	451.0519511
F/W Calculation	
$m_{tot\text{-}initial}$ (kg)	7,476,932.95
$Thrust_{tot\text{-}SSME's}$ (N)	6,522,858.00
$Thrust_{tot\text{-}SRM's}$ (N)	23,600,000.00
F/W	**0.410680121**

Stage 2

SSME's	
$mdot_{tot\text{-}SSME\text{-}1}$ (kg/s) (104%)	1,461.36
$t_{burn\ stage\text{-}2}$(s) preburn	388.00
$m_{prop\text{-}SSME\text{-}stg2}$ (kg)	567,008.08
$m_{prop\text{-}LH\text{-}SSME\text{-}stg2}$ (kg)	81,001.15
$m_{prop\text{-}OX\text{-}SSME\text{-}stg2}$ (kg)	486,006.92
ET	
$m_{tank\text{-}LH}$ (kg)	1,148,202.75
$m_{tank\text{-}OX}$ (kg)	505,679.88
$m_{tank\text{-}press}$ (kg)	581,730.09
m_{press} (kg)	3,234,838.23
$m_{LH\text{-}tot}$ (kg)	76,859.77
$m_{OX\text{-}tot}$ (kg)	465,658.64
$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00
ΔV calculation	
$Isp_{stage\text{-}2}$ (s)	455.00
$m_{prop\text{-}tot}$ (kg)	567,008.08
$m_{inert\text{-}tot}$ (kg)	5,482,250.95
$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	431.4700707
ΔV_{tot} (m/s)	**882.5220218**
F/W Calculation	
$m_{tot\text{-}initial}$ (kg)	6,153,759.03
$Thrust_{tot\text{-}SSME's}$ (N)	6,522,858.00
F/W	**0.108050911**

TABLE B.11

ΔV & T/W Calculations
For Argon Pressurant, Sit. 1

Stage 1		Stage 2	
SSME's		**SSME's**	
mdot$_{\text{tot-SSME-1}}$ (kg/s) (90%)	1,264.64	mdot$_{\text{tot-SSME-1}}$ (kg/s) (104%)	1,461.36
mdot$_{\text{tot-SSME-2}}$ (kg/s) (100%)	1,405.15	t$_{\text{burn stage-2}}$(s) preburn	388.00
mdot$_{\text{tot-SSME-3}}$ (kg/s) (70%)	983.61	m$_{\text{prop-SSME-stg2}}$ (kg)	567,008.08
mdot$_{\text{tot-SSME-4}}$ (kg/s) (104%)	1,461.36	m$_{\text{prop-LH-SSME-stg2}}$ (kg)	81,001.15
t$_{\text{burn stg1-1}}$(s) preburn	6.60	m$_{\text{prop-OX-SSME-stg2}}$ (kg)	486,006.92
t$_{\text{burn stg1-2}}$(s) liftoff	30.00		
t$_{\text{burn stg1-3}}$(s) throttle back	31.00		
t$_{\text{burn stg1-4}}$(s) throttle back	65.00		
m$_{\text{prop-SSME-stg1}}$ (kg)	175,981.59		
m$_{\text{prop-LH-SSME-stg1}}$ (kg)	25,140.23		
m$_{\text{prop-OX-SSME-stg1}}$ (kg)	150,841.36		
ET		**ET**	
m$_{\text{tank-LH}}$ (kg)	1,148,202.75	m$_{\text{tank-LH}}$ (kg)	1,148,202.75
m$_{\text{tank-OX}}$ (kg)	505,679.88	m$_{\text{tank-OX}}$ (kg)	505,679.88
m$_{\text{tank-press}}$ (kg)	3,927,571.38	m$_{\text{tank-press}}$ (kg)	3,927,571.38
m$_{\text{press}}$ (kg)	6,216,035.63	m$_{\text{press}}$ (kg)	6,216,035.63
m$_{\text{LH-tot}}$ (kg)	102,000.00	m$_{\text{LH-tot}}$ (kg)	76,859.77
m$_{\text{OX-tot}}$ (kg)	616,500.00	m$_{\text{OX-tot}}$ (kg)	465,658.64
m$_{\text{inter-tank}}$ (kg)	5,487.00	m$_{\text{inter-tank}}$ (kg)	5,487.00
m$_{\text{thermal-prot}}$ (kg)	2,187.00	m$_{\text{thermal-prot}}$ (kg)	2,187.00
m$_{\text{external-HW}}$ (kg)	4,126.00	m$_{\text{external-HW}}$ (kg)	4,126.00
SRM's			
m$_{\text{booster tot inert}}$ (kg)	174,120.00		
m$_{\text{booster tot wet}}$ (kg)	1,171,682.00		
m$_{\text{SRM-prop-tot}}$ (kg)	997,562.00		
ΔV calculation		**ΔV calculation**	
Isp$_{\text{stage-1}}$ (s)	269.30	Isp$_{\text{stage-2}}$ (s)	455.00
m$_{\text{prop-tot}}$ (kg)	1,173,543.59	m$_{\text{prop-tot}}$ (kg)	567,008.08
m$_{\text{inert-tot}}$ (kg)	12,525,928.05	m$_{\text{inert-tot}}$ (kg)	11,809,289.64
m$_{\text{orb w/P/L}}$ (kg)	104,500.00	m$_{\text{orb w/P/L}}$ (kg)	104,500.00
ΔV (m/s)	234.7193235	ΔV (m/s)	207.5316772
		ΔV$_{\text{tot}}$ (m/s)	**442.2510007**
F/W Calculation		**F/W Calculation**	
m$_{\text{tot-initial}}$ (kg)	13,803,971.64	m$_{\text{tot-initial}}$ (kg)	12,480,797.72
Thrust$_{\text{tot-SSME's}}$ (N)	6,522,858.00	Thrust$_{\text{tot-SSME's}}$ (N)	6,522,858.00
Thrust$_{\text{tot-SRM's}}$ (N)	23,600,000.00		
F/W	**0.222445236**	**F/W**	**0.053275382**

TABLE B.12

ΔV & T/W Calculations
For Argon Pressurant, Sit. 2

Stage 1

SSME's	
$mdot_{\text{tot-SSME-1}}$ (kg/s) (90%)	1,264.64
$mdot_{\text{tot-SSME-2}}$ (kg/s) (100%)	1,405.15
$mdot_{\text{tot-SSME-3}}$ (kg/s) (70%)	983.61
$mdot_{\text{tot-SSME-4}}$ (kg/s) (104%)	1,461.36
$t_{\text{burn stg1-1}}$(s) preburn	6.60
$t_{\text{burn stg1-2}}$(s) liftoff	30.00
$t_{\text{burn stg1-3}}$(s) throttle back	31.00
$t_{\text{burn stg1-4}}$(s) throttle back	65.00
$m_{\text{prop-SSME-stg1}}$ (kg)	175,981.59
$m_{\text{prop-LH-SSME-stg1}}$ (kg)	25,140.23
$m_{\text{prop-OX-SSME-stg1}}$ (kg)	150,841.36

ET	
$m_{\text{tank-LH}}$ (kg)	1,148,202.75
$m_{\text{tank-OX}}$ (kg)	505,679.88
$m_{\text{tank-press}}$ (kg)	785,514.28
m_{press} (kg)	6,216,035.63
$m_{\text{LH-tot}}$ (kg)	102,000.00
$m_{\text{OX-tot}}$ (kg)	616,500.00
$m_{\text{inter-tank}}$ (kg)	5,487.00
$m_{\text{thermal-prot}}$ (kg)	2,187.00
$m_{\text{external-HW}}$ (kg)	4,126.00

SRM's	
$m_{\text{booster tot inert}}$ (kg)	174,120.00
$m_{\text{booster tot wet}}$ (kg)	1,171,682.00
$m_{\text{SRM-prop-tot}}$ (kg)	997,562.00

ΔV calculation	
$Isp_{\text{stage-1}}$ (s)	269.30
$m_{\text{prop-tot}}$ (kg)	1,173,543.59
$m_{\text{inert-tot}}$ (kg)	9,383,870.95
$m_{\text{orb w/P/L}}$ (kg)	104,500.00
ΔV (m/s)	308.065652

F/W Calculation	
$m_{\text{tot-initial}}$ (kg)	10,661,914.54
$Thrust_{\text{tot-SSME's}}$ (N)	6,522,858.00
$Thrust_{\text{tot-SRM's}}$ (N)	23,600,000.00
F/W	**0.287999657**

Stage 2

SSME's	
$mdot_{\text{tot-SSME-1}}$ (kg/s) (104%)	1,461.36
$t_{\text{burn stage-2}}$(s) preburn	388.00
$m_{\text{prop-SSME-stg2}}$ (kg)	567,008.08
$m_{\text{prop-LH-SSME-stg2}}$ (kg)	81,001.15
$m_{\text{prop-OX-SSME-stg2}}$ (kg)	486,006.92

ET	
$m_{\text{tank-LH}}$ (kg)	1,148,202.75
$m_{\text{tank-OX}}$ (kg)	505,679.88
$m_{\text{tank-press}}$ (kg)	785,514.28
m_{press} (kg)	6,216,035.63
$m_{\text{LH-tot}}$ (kg)	76,859.77
$m_{\text{OX-tot}}$ (kg)	465,658.64
$m_{\text{inter-tank}}$ (kg)	5,487.00
$m_{\text{thermal-prot}}$ (kg)	2,187.00
$m_{\text{external-HW}}$ (kg)	4,126.00

ΔV calculation	
$Isp_{\text{stage-2}}$ (s)	455.00
$m_{\text{prop-tot}}$ (kg)	567,008.08
$m_{\text{inert-tot}}$ (kg)	8,667,232.54
$m_{\text{orb w/P/L}}$ (kg)	104,500.00
ΔV (m/s)	279.5836747
ΔV_{tot} (m/s)	**587.6493267**

F/W Calculation	
$m_{\text{tot-initial}}$ (kg)	9,338,740.62
$Thrust_{\text{tot-SSME's}}$ (N)	6,522,858.00
F/W	**0.0712001**

APPENDIX C

CHART C.3

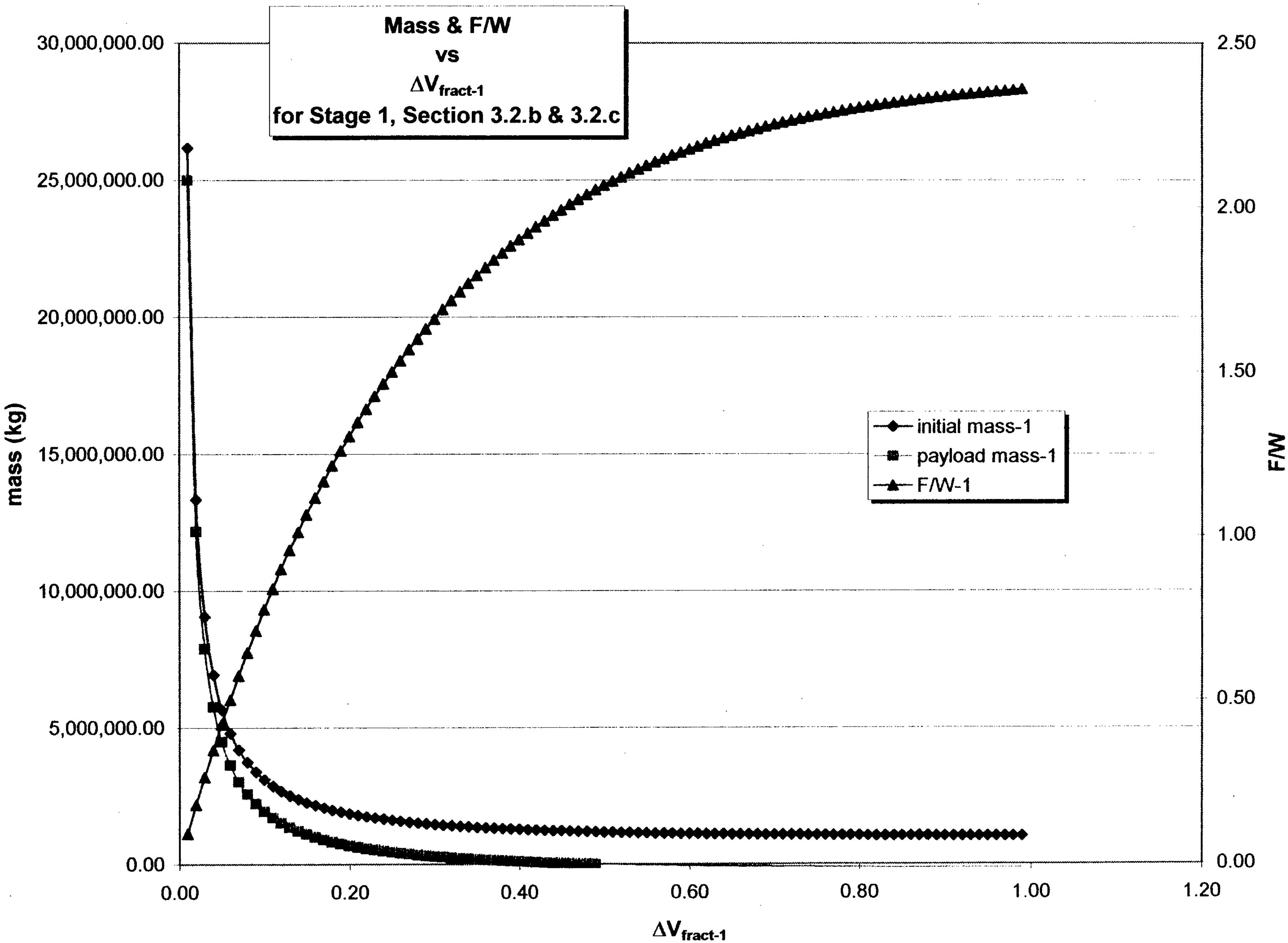

Mass & F/W
vs
ΔV fract-1
for Stage 1, Section 3.2.b & 3.2.c
mass (kg)
30,000,000.00
25,000,000.00
20,000,000.00
15,000,000.00
10,000,000.00
5,000,000.00
0.00
F/W
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
ΔV fract-1
initial mass-1
payload mass-1
F/W-1

TABLE C.3

Calculations for Stage 1, Section 3.2.b & 3.2.c

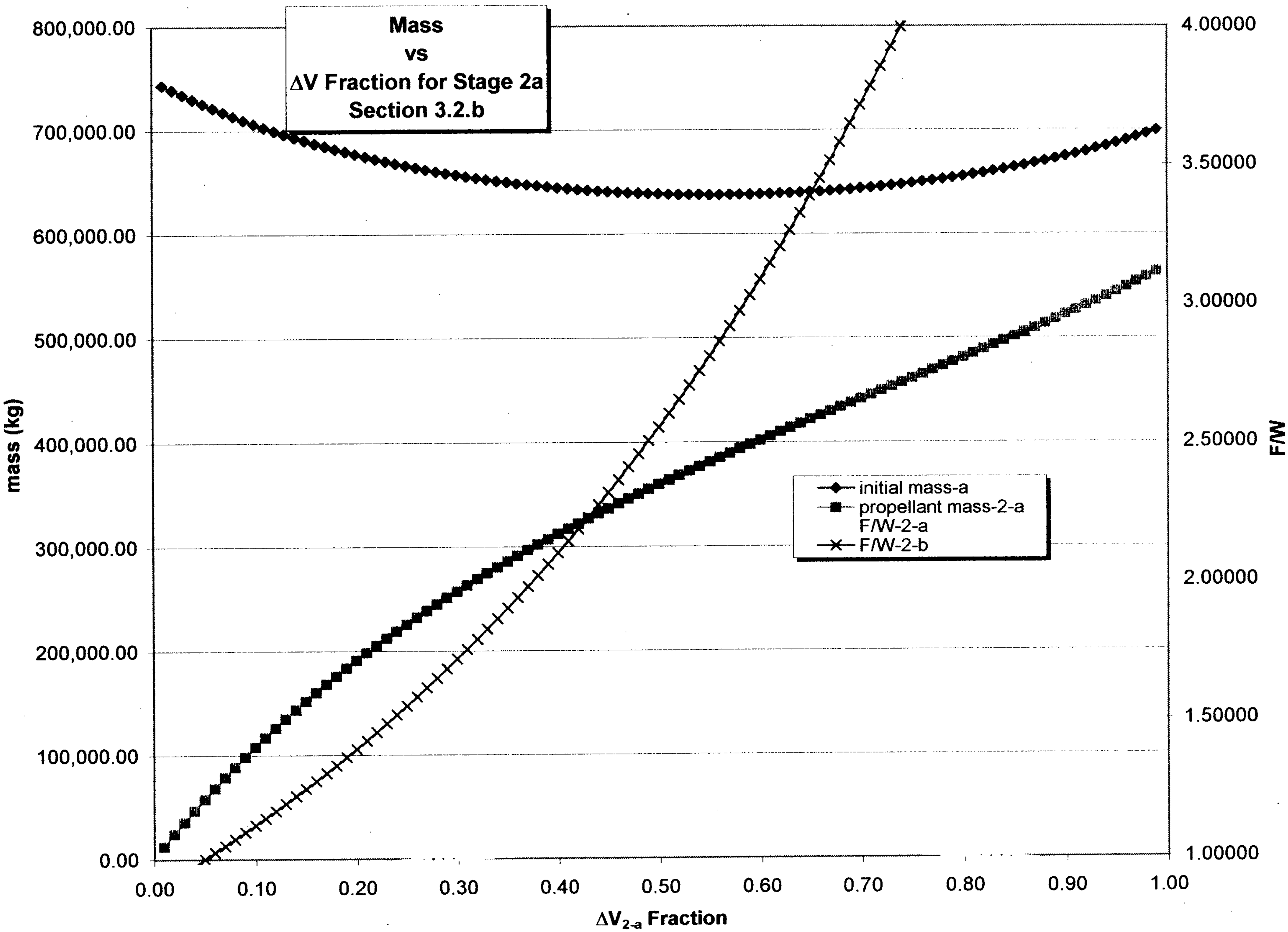
Isp_1 (s)	242.00	F/W_{design}	1.30	Isp_2 (s)	455.00
m_{prop-1} (kg)	997,562.00	$m_{pay-allowed}$ (kg)	678,862.97		
$m_{inert-1}$ (kg)	174,120.00			m_{pay-2} (kg)	104,500.00
ΔV_{tot} (m/s)	9,230.00				

ΔV_{1fract} (m/s)	ΔV_1 (m/s)	m_{i-1} (kg)	m_{f-1} (kg)	m_{pay-1} (kg)	T_1 (N)	F/W_1	ΔV_{2fract} (m/s)	ΔV_2 (m/s)	m_{i-2} (kg)	m_{f-2} (kg)	T_2 (N)
0.01	92.30	26,159,999.29	25,162,437.29	24,988,317.29	23,600,000.00	0.09	0.99	9,137.70	24,988,317.29	3,225,945.97	6,522,858.00
0.02	184.60	13,334,237.59	12,336,675.59	12,162,555.59	23,600,000.00	0.18	0.98	9,045.40	12,162,555.59	1,602,970.47	6,522,858.00
0.03	276.90	9,061,137.02	8,063,575.02	7,889,455.02	23,600,000.00	0.27	0.97	8,953.10	7,889,455.02	1,061,520.27	6,522,858.00
0.04	369.20	6,926,200.51	5,928,638.51	5,754,518.51	23,600,000.00	0.35	0.96	8,860.80	5,754,518.51	790,443.60	6,522,858.00
0.05	461.50	5,646,528.27	4,648,966.27	4,474,846.27	23,600,000.00	0.43	0.95	8,768.50	4,474,846.27	627,509.95	6,522,858.00
0.06	553.80	4,794,486.70	3,796,924.70	3,622,804.70	23,600,000.00	0.50	0.94	8,676.20	3,622,804.70	518,642.41	6,522,858.00
0.07	646.10	4,186,803.98	3,189,241.98	3,015,121.98	23,600,000.00	0.57	0.93	8,583.90	3,015,121.98	440,665.04	6,522,858.00
0.08	738.40	3,731,843.97	2,734,281.97	2,560,161.97	23,600,000.00	0.64	0.92	8,491.60	2,560,161.97	381,989.79	6,522,858.00
0.09	830.70	3,378,697.49	2,381,135.49	2,207,015.49	23,600,000.00	0.71	0.91	8,399.30	2,207,015.49	336,178.78	6,522,858.00
0.10	923.00	3,096,818.85	2,099,256.85	1,925,136.85	23,600,000.00	0.78	0.90	8,307.00	1,925,136.85	299,369.21	6,522,858.00
0.11	1,015.30	2,866,769.68	1,869,207.68	1,695,087.68	23,600,000.00	0.84	0.89	8,214.70	1,695,087.68	269,102.85	6,522,858.00
0.12	1,107.60	2,675,590.96	1,678,028.96	1,503,908.96	23,600,000.00	0.90	0.88	8,122.40	1,503,908.96	243,740.83	6,522,858.00
0.13	1,199.90	2,514,310.89	1,516,748.89	1,342,628.89	23,600,000.00	0.96	0.87	8,030.10	1,342,628.89	222,148.47	6,522,858.00
0.14	1,292.20	2,376,520.93	1,378,958.93	1,204,838.93	23,600,000.00	1.01	0.86	7,937.80	1,204,838.93	203,515.24	6,522,858.00
0.15	1,384.50	2,257,521.34	1,259,959.34	1,085,839.34	23,600,000.00	1.07	0.85	7,845.50	1,085,839.34	187,246.68	6,522,858.00
0.16	1,476.80	2,153,787.22	1,156,225.22	982,105.22	23,600,000.00	1.12	0.84	7,753.20	982,105.22	172,896.89	6,522,858.00
0.17	1,569.10	2,062,622.97	1,065,060.97	890,940.97	23,600,000.00	1.17	0.83	7,660.90	890,940.97	160,124.83	6,522,858.00
0.18	1,661.40	1,981,931.90	984,369.90	810,249.90	23,600,000.00	1.21	0.82	7,568.60	810,249.90	148,665.21	6,522,858.00
0.19	1,753.70	1,910,058.65	912,496.65	738,376.65	23,600,000.00	1.26	0.81	7,476.30	738,376.65	138,308.52	6,522,858.00
0.20	1,846.00	1,845,678.84	848,116.84	673,996.84	23,600,000.00	1.30	0.80	7,384.00	673,996.84	128,887.10	6,522,858.00
0.21	1,938.30	1,787,720.29	790,158.29	616,038.29	23,600,000.00	1.35	0.79	7,291.70	616,038.29	120,265.18	6,522,858.00
0.22	2,030.60	1,735,305.68	737,743.68	563,623.68	23,600,000.00	1.39	0.78	7,199.40	563,623.68	112,331.62	6,522,858.00
0.23	2,122.90	1,687,710.21	690,148.21	516,028.21	23,600,000.00	1.43	0.77	7,107.10	516,028.21	104,994.57	6,522,858.00
0.24	2,215.20	1,644,329.80	646,767.80	472,647.80	23,600,000.00	1.46	0.76	7,014.80	472,647.80	98,177.43	6,522,858.00
0.25	2,307.50	1,604,657.00	607,095.00	432,975.00	23,600,000.00	1.50	0.75	6,922.50	432,975.00	91,815.80	6,522,858.00
0.26	2,399.80	1,568,262.34	570,700.34	396,580.34	23,600,000.00	1.53	0.74	6,830.20	396,580.34	85,855.16	6,522,858.00
0.27	2,492.10	1,534,779.95	537,217.95	363,097.95	23,600,000.00	1.57	0.73	6,737.90	363,097.95	80,249.00	6,522,858.00
0.28	2,584.40	1,503,896.16	506,334.16	332,214.16	23,600,000.00	1.60	0.72	6,645.60	332,214.16	74,957.41	6,522,858.00
0.29	2,676.70	1,475,340.52	477,778.52	303,658.52	23,600,000.00	1.63	0.71	6,553.30	303,658.52	69,945.94	6,522,858.00
0.30	2,769.00	1,448,878.63	451,316.63	277,196.63	23,600,000.00	1.66	0.70	6,461.00	277,196.63	65,184.69	6,522,858.00
0.31	2,861.30	1,424,306.26	426,744.26	252,624.26	23,600,000.00	1.69	0.69	6,368.70	252,624.26	60,647.56	6,522,858.00
0.32	2,953.60	1,401,444.70	403,882.70	229,762.70	23,600,000.00	1.72	0.68	6,276.40	229,762.70	56,311.66	6,522,858.00
0.33	3,045.90	1,380,136.85	382,574.85	208,454.85	23,600,000.00	1.74	0.67	6,184.10	208,454.85	52,156.86	6,522,858.00
0.34	3,138.20	1,360,244.07	362,682.07	188,562.07	23,600,000.00	1.77	0.66	6,091.80	188,562.07	48,165.31	6,522,858.00
0.35	3,230.50	1,341,643.53	344,081.53	169,961.53	23,600,000.00	1.79	0.65	5,999.50	169,961.53	44,321.18	6,522,858.00
0.36	3,322.80	1,324,226.03	326,664.03	152,544.03	23,600,000.00	1.82	0.64	5,907.20	152,544.03	40,610.33	6,522,858.00
0.37	3,415.10	1,307,894.15	310,332.15	136,212.15	23,600,000.00	1.84	0.63	5,814.90	136,212.15	37,020.11	6,522,858.00
0.38	3,507.40	1,292,560.70	294,998.70	120,878.70	23,600,000.00	1.86	0.62	5,722.60	120,878.70	33,539.16	6,522,858.00
0.39	3,599.70	1,278,147.40	280,585.40	106,465.40	23,600,000.00	1.88	0.61	5,630.30	106,465.40	30,157.24	6,522,858.00
0.40	3,692.00	1,264,583.80	267,021.80	92,901.80	23,600,000.00	1.90	0.60	5,538.00	92,901.80	26,865.06	6,522,858.00
0.41	3,784.30	1,251,806.29	254,244.29	80,124.29	23,600,000.00	1.92	0.59	5,445.70	80,124.29	23,654.21	6,522,858.00
0.42	3,876.60	1,239,757.32	242,195.32	68,075.32	23,600,000.00	1.94	0.58	5,353.40	68,075.32	20,517.03	6,522,858.00
0.43	3,968.90	1,228,384.65	230,822.65	56,702.65	23,600,000.00	1.96	0.57	5,261.10	56,702.65	17,446.52	6,522,858.00
0.44	4,061.20	1,217,640.80	220,078.80	45,958.80	23,600,000.00	1.98	0.56	5,168.80	45,958.80	14,436.26	6,522,858.00
0.45	4,153.50	1,207,482.49	209,920.49	35,800.49	23,600,000.00	1.99	0.55	5,076.50	35,800.49	11,480.37	6,522,858.00
0.46	4,245.80	1,197,870.20	200,308.20	26,188.20	23,600,000.00	2.01	0.54	4,984.20	26,188.20	8,573.40	6,522,858.00

TABLE C.3

0.47	4,338.10	1,188,767.76	191,205.76	17,085.76	23,600,000.00	2.02	0.53	4,891.90	17,085.76	5,710.34	6,522,858.00
0.48	4,430.40	1,180,142.00	182,580.00	8,460.00	23,600,000.00	2.04	0.52	4,799.60	8,460.00	2,886.55	6,522,858.00
0.49	4,522.70	1,171,962.45	174,400.45	280.45	23,600,000.00	2.05	0.51	4,707.30	280.45	97.69	6,522,858.00
0.50	4,615.00	1,164,201.09	166,639.09	-7,480.91	23,600,000.00	2.07	0.50	4,615.00	-7,480.91	-2,660.26	6,522,858.00
0.51	4,707.30	1,156,832.07	159,270.07	-14,849.93	23,600,000.00	2.08	0.49	4,522.70	-14,849.93	-5,391.07	6,522,858.00
0.52	4,799.60	1,149,831.55	152,269.55	-21,850.45	23,600,000.00	2.09	0.48	4,430.40	-21,850.45	-8,098.25	6,522,858.00
0.53	4,891.90	1,143,177.45	145,615.45	-28,504.55	23,600,000.00	2.10	0.47	4,338.10	-28,504.55	-10,785.14	6,522,858.00
0.54	4,984.20	1,136,849.36	139,287.36	-34,832.64	23,600,000.00	2.12	0.46	4,245.80	-34,832.64	-13,454.84	6,522,858.00
0.55	5,076.50	1,130,828.34	133,266.34	-40,853.66	23,600,000.00	2.13	0.45	4,153.50	-40,853.66	-16,110.31	6,522,858.00
0.56	5,168.80	1,125,096.78	127,534.78	-46,585.22	23,600,000.00	2.14	0.44	4,061.20	-46,585.22	-18,754.33	6,522,858.00
0.57	5,261.10	1,119,638.34	122,076.34	-52,043.66	23,600,000.00	2.15	0.43	3,968.90	-52,043.66	-21,389.56	6,522,858.00
0.58	5,353.40	1,114,437.78	116,875.78	-57,244.22	23,600,000.00	2.16	0.42	3,876.60	-57,244.22	-24,018.52	6,522,858.00
0.59	5,445.70	1,109,480.92	111,918.92	-62,201.08	23,600,000.00	2.17	0.41	3,784.30	-62,201.08	-26,643.61	6,522,858.00
0.60	5,538.00	1,104,754.51	107,192.51	-66,927.49	23,600,000.00	2.18	0.40	3,692.00	-66,927.49	-29,267.14	6,522,858.00
0.61	5,630.30	1,100,246.17	102,684.17	-71,435.83	23,600,000.00	2.19	0.39	3,599.70	-71,435.83	-31,891.32	6,522,858.00
0.62	5,722.60	1,095,944.33	98,382.33	-75,737.67	23,600,000.00	2.20	0.38	3,507.40	-75,737.67	-34,518.26	6,522,858.00
0.63	5,814.90	1,091,838.15	94,276.15	-79,843.85	23,600,000.00	2.20	0.37	3,415.10	-79,843.85	-37,150.02	6,522,858.00
0.64	5,907.20	1,087,917.49	90,355.49	-83,764.51	23,600,000.00	2.21	0.36	3,322.80	-83,764.51	-39,788.57	6,522,858.00
0.65	5,999.50	1,084,172.80	86,610.80	-87,509.20	23,600,000.00	2.22	0.35	3,230.50	-87,509.20	-42,435.81	6,522,858.00
0.66	6,091.80	1,080,595.16	83,033.16	-91,086.84	23,600,000.00	2.23	0.34	3,138.20	-91,086.84	-45,093.62	6,522,858.00
0.67	6,184.10	1,077,176.14	79,614.14	-94,505.86	23,600,000.00	2.23	0.33	3,045.90	-94,505.86	-47,763.79	6,522,858.00
0.68	6,276.40	1,073,907.86	76,345.86	-97,774.14	23,600,000.00	2.24	0.32	2,953.60	-97,774.14	-50,448.08	6,522,858.00
0.69	6,368.70	1,070,782.87	73,220.87	-100,899.13	23,600,000.00	2.25	0.31	2,861.30	-100,899.13	-53,148.21	6,522,858.00
0.70	6,461.00	1,067,794.15	70,232.15	-103,887.85	23,600,000.00	2.25	0.30	2,769.00	-103,887.85	-55,865.87	6,522,858.00
0.71	6,553.30	1,064,935.10	67,373.10	-106,746.90	23,600,000.00	2.26	0.29	2,676.70	-106,746.90	-58,602.71	6,522,858.00
0.72	6,645.60	1,062,199.49	64,637.49	-109,482.51	23,600,000.00	2.26	0.28	2,584.40	-109,482.51	-61,360.35	6,522,858.00
0.73	6,737.90	1,059,581.42	62,019.42	-112,100.58	23,600,000.00	2.27	0.27	2,492.10	-112,100.58	-64,140.38	6,522,858.00
0.74	6,830.20	1,057,075.34	59,513.34	-114,606.66	23,600,000.00	2.28	0.26	2,399.80	-114,606.66	-66,944.38	6,522,858.00
0.75	6,922.50	1,054,675.97	57,113.97	-117,006.03	23,600,000.00	2.28	0.25	2,307.50	-117,006.03	-69,773.92	6,522,858.00
0.76	7,014.80	1,052,378.36	54,816.36	-119,303.64	23,600,000.00	2.29	0.24	2,215.20	-119,303.64	-72,630.52	6,522,858.00
0.77	7,107.10	1,050,177.79	52,615.79	-121,504.21	23,600,000.00	2.29	0.23	2,122.90	-121,504.21	-75,515.73	6,522,858.00
0.78	7,199.40	1,048,069.80	50,507.80	-123,612.20	23,600,000.00	2.30	0.22	2,030.60	-123,612.20	-78,431.05	6,522,858.00
0.79	7,291.70	1,046,050.17	48,488.17	-125,631.83	23,600,000.00	2.30	0.21	1,938.30	-125,631.83	-81,378.00	6,522,858.00
0.80	7,384.00	1,044,114.87	46,552.87	-127,567.13	23,600,000.00	2.30	0.20	1,846.00	-127,567.13	-84,358.08	6,522,858.00
0.81	7,476.30	1,042,260.13	44,698.13	-129,421.87	23,600,000.00	2.31	0.19	1,753.70	-129,421.87	-87,372.79	6,522,858.00
0.82	7,568.60	1,040,482.31	42,920.31	-131,199.69	23,600,000.00	2.31	0.18	1,661.40	-131,199.69	-90,423.62	6,522,858.00
0.83	7,660.90	1,038,778.00	41,216.00	-132,904.00	23,600,000.00	2.32	0.17	1,569.10	-132,904.00	-93,512.09	6,522,858.00
0.84	7,753.20	1,037,143.95	39,581.95	-134,538.05	23,600,000.00	2.32	0.16	1,476.80	-134,538.05	-96,639.67	6,522,858.00
0.85	7,845.50	1,035,577.05	38,015.05	-136,104.95	23,600,000.00	2.32	0.15	1,384.50	-136,104.95	-99,807.89	6,522,858.00
0.86	7,937.80	1,034,074.36	36,512.36	-137,607.64	23,600,000.00	2.33	0.14	1,292.20	-137,607.64	-103,018.23	6,522,858.00
0.87	8,030.10	1,032,633.08	35,071.08	-139,048.92	23,600,000.00	2.33	0.13	1,199.90	-139,048.92	-106,272.22	6,522,858.00
0.88	8,122.40	1,031,250.54	33,688.54	-140,431.46	23,600,000.00	2.33	0.12	1,107.60	-140,431.46	-109,571.38	6,522,858.00
0.89	8,214.70	1,029,924.22	32,362.22	-141,757.78	23,600,000.00	2.34	0.11	1,015.30	-141,757.78	-112,917.24	6,522,858.00
0.90	8,307.00	1,028,651.69	31,089.69	-143,030.31	23,600,000.00	2.34	0.10	923.00	-143,030.31	-116,311.33	6,522,858.00
0.91	8,399.30	1,027,430.64	29,868.64	-144,251.36	23,600,000.00	2.34	0.09	830.70	-144,251.36	-119,755.22	6,522,858.00
0.92	8,491.60	1,026,258.89	28,696.89	-145,423.11	23,600,000.00	2.34	0.08	738.40	-145,423.11	-123,250.47	6,522,858.00
0.93	8,583.90	1,025,134.35	27,572.35	-146,547.65	23,600,000.00	2.35	0.07	646.10	-146,547.65	-126,798.65	6,522,858.00
0.94	8,676.20	1,024,055.00	26,493.00	-147,627.00	23,600,000.00	2.35	0.06	553.80	-147,627.00	-130,401.37	6,522,858.00
0.95	8,768.50	1,023,018.96	25,456.96	-148,663.04	23,600,000.00	2.35	0.05	461.50	-148,663.04	-134,060.24	6,522,858.00
0.96	8,860.80	1,022,024.40	24,462.40	-149,657.60	23,600,000.00	2.35	0.04	369.20	-149,657.60	-137,776.88	6,522,858.00
0.97	8,953.10	1,021,069.59	23,507.59	-150,612.41	23,600,000.00	2.36	0.03	276.90	-150,612.41	-141,552.95	6,522,858.00
0.98	9,045.40	1,020,152.88	22,590.88	-151,529.12	23,600,000.00	2.36	0.02	184.60	-151,529.12	-145,390.12	6,522,858.00
0.99	9,137.70	1,019,272.67	21,710.67	-152,409.33	23,600,000.00	2.36	0.01	92.30	-152,409.33	-149,290.08	6,522,858.00

CHART C.4



Mass
vs
ΔV Fraction for Stage 2a
Section 3.2.b
800,000.00
700,000.00
600,000.00
500,000.00
400,000.00
300,000.00
200,000.00
100,000.00
0.00
mass (kg)
4.00000
3.50000
3.00000
2.50000
2.00000
1.50000
1.00000
F/W
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
ΔV2-a Fraction
initial mass-a
propellant mass-2-a
F/W-2-a
F/W-2-b

TABLE C.4

Calculations for Stage 2a & 2b for Section 3.2.b

Isp_2 (s)	455.00
$\Delta V_{2\text{-tot}}$ (m/s)	7,384.00
$m_{i\text{-2a-allowed}}$ (kg)	673,996.84
$f_{inert\text{-2a}}$	0.05
T_{2a} (N)	6,522,858.00

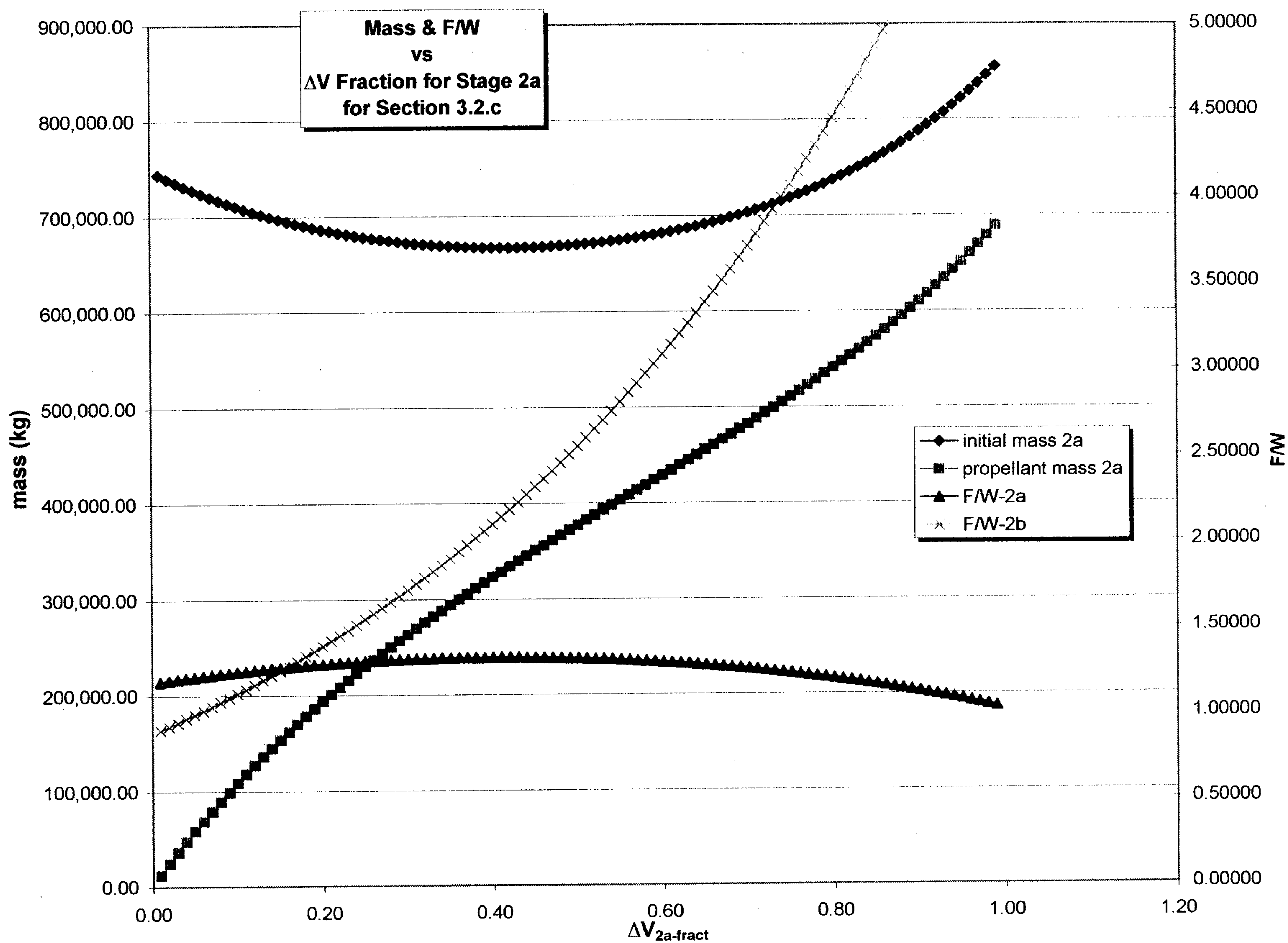
Isp_2 (s)	455.00
$f_{inert\text{-2b}}$	0.06
$m_{pay\text{-2b}}$ (kg)	104,500.00
T_{2b} (N)	6,522,858.00

$\Delta V_{2a\text{-fract}}$ (m/s)	ΔV_{2a} (m/s)	$m_{prop\text{-2a}}$ (kg)	$m_{inert\text{-2a}}$ (kg)	$m_{pay\text{-2a}}$ (kg)	$m_{i\text{-2a}}$ (kg)	$m_{f\text{-2a}}$ (kg)	F/W_{2a}	$m_{i\text{-allowed}}$ Test	$\Delta V_{2b\text{-fract}}$ (m/s)	ΔV_{2b} (m/s)	$m_{prop\text{-2b}}$ (kg)	$m_{inert\text{-2b}}$ (kg)	$m_{pay\text{-2a}}$ (kg)	$m_{i\text{-2b}}$ (kg)	$m_{f\text{-2b}}$ (kg)	F/W_{2b}
0.01	73.840	12,200.49	642.13	730,781.10	743,623.72	731,423.23	0.89416	no	0.99	7,310.16	588,704.23	37,576.87	104,500.00	730,781.10	142,076.87	0.91
0.02	147.680	24,046.34	1,265.60	713,565.52	738,877.46	714,831.12	0.89990	no	0.98	7,236.32	572,521.59	36,543.93	104,500.00	713,565.52	141,043.93	0.93
0.03	221.520	35,552.75	1,871.20	696,874.86	734,298.81	698,746.06	0.90552	no	0.97	7,162.48	556,832.37	35,542.49	104,500.00	696,874.86	140,042.49	0.95
0.04	295.360	46,734.10	2,459.69	680,687.65	729,881.44	683,147.34	0.91100	no	0.96	7,088.64	541,616.39	34,571.26	104,500.00	680,687.65	139,071.26	0.98
0.05	369.200	57,604.01	3,031.79	664,983.57	725,619.37	668,015.36	0.91635	no	0.95	7,014.80	526,854.55	33,629.01	104,500.00	664,983.57	138,129.01	1.00
0.06	443.040	68,175.43	3,588.18	649,743.35	721,506.96	653,331.53	0.92157	no	0.94	6,940.96	512,528.75	32,714.60	104,500.00	649,743.35	137,214.60	1.02
0.07	516.880	78,460.61	4,129.51	634,948.75	717,538.86	639,078.25	0.92667	no	0.93	6,867.12	498,621.82	31,826.92	104,500.00	634,948.75	136,326.92	1.05
0.08	590.720	88,471.22	4,656.38	620,582.43	713,710.03	625,238.81	0.93164	no	0.92	6,793.28	485,117.48	30,964.95	104,500.00	620,582.43	135,464.95	1.07
0.09	664.560	98,218.34	5,169.39	606,627.95	710,015.68	611,797.34	0.93649	no	0.91	6,719.44	472,000.27	30,127.68	104,500.00	606,627.95	134,627.68	1.10
0.10	738.400	107,712.52	5,669.08	593,069.68	706,451.27	598,738.76	0.94121	no	0.90	6,645.60	459,255.50	29,314.18	104,500.00	593,069.68	133,814.18	1.12
0.11	812.240	116,963.79	6,155.99	579,892.75	703,012.52	586,048.74	0.94581	no	0.89	6,571.76	446,869.18	28,523.56	104,500.00	579,892.75	133,023.56	1.15
0.12	886.080	125,981.71	6,630.62	567,083.03	699,695.36	573,713.65	0.95030	no	0.88	6,497.92	434,828.05	27,754.98	104,500.00	567,083.03	132,254.98	1.17
0.13	959.920	134,775.41	7,093.44	554,627.06	696,495.92	561,720.51	0.95466	no	0.87	6,424.08	423,119.44	27,007.62	104,500.00	554,627.06	131,507.62	1.20
0.14	1,033.760	143,353.59	7,544.93	542,512.03	693,410.54	550,056.96	0.95891	no	0.86	6,350.24	411,731.31	26,280.72	104,500.00	542,512.03	130,780.72	1.23
0.15	1,107.600	151,724.55	7,985.50	530,725.71	690,435.76	538,711.21	0.96304	no	0.85	6,276.40	400,652.17	25,573.54	104,500.00	530,725.71	130,073.54	1.25
0.16	1,181.440	159,896.24	8,415.59	519,256.46	687,568.29	527,672.05	0.96706	no	0.84	6,202.56	389,871.07	24,885.39	104,500.00	519,256.46	129,385.39	1.28
0.17	1,255.280	167,876.24	8,835.59	508,093.15	684,804.98	516,928.74	0.97096	no	0.83	6,128.72	379,377.56	24,215.59	104,500.00	508,093.15	128,715.59	1.31
0.18	1,329.120	175,671.82	9,245.89	497,225.17	682,142.88	506,471.06	0.97475	no	0.82	6,054.88	369,161.66	23,563.51	104,500.00	497,225.17	128,063.51	1.34
0.19	1,402.960	183,289.93	9,646.84	486,642.40	679,579.16	496,289.23	0.97843	no	0.81	5,981.04	359,213.85	22,928.54	104,500.00	486,642.40	127,428.54	1.37
0.20	1,476.800	190,737.23	10,038.80	476,335.13	677,111.16	486,373.93	0.98199	no	0.80	5,907.20	349,525.02	22,310.11	104,500.00	476,335.13	126,810.11	1.40
0.21	1,550.640	198,020.11	10,422.11	466,294.10	674,736.32	476,716.21	0.98545	no	0.79	5,833.36	340,086.45	21,707.65	104,500.00	466,294.10	126,207.65	1.43
0.22	1,624.480	205,144.70	10,797.09	456,510.45	672,452.24	467,307.54	0.98880	yes	0.78	5,759.52	330,889.83	21,120.63	104,500.00	456,510.45	125,620.63	1.46
0.23	1,698.320	212,116.87	11,164.05	446,975.71	670,256.62	458,139.75	0.99204	yes	0.77	5,685.68	321,927.16	20,548.54	104,500.00	446,975.71	125,048.54	1.49
0.24	1,772.160	218,942.28	11,523.28	437,681.73	668,147.29	449,205.01	0.99517	yes	0.76	5,611.84	313,190.83	19,990.90	104,500.00	437,681.73	124,490.90	1.52
0.25	1,846.000	225,626.37	11,875.07	428,620.75	666,122.19	440,495.83	0.99819	yes	0.75	5,538.00	304,673.51	19,447.25	104,500.00	428,620.75	123,947.25	1.55
0.26	1,919.840	232,174.35	12,219.70	419,785.31	664,179.36	432,005.01	1.00111	yes	0.74	5,464.16	296,368.19	18,917.12	104,500.00	419,785.31	123,417.12	1.58
0.27	1,993.680	238,591.25	12,557.43	411,168.24	662,316.93	423,725.68	1.00393	yes	0.73	5,390.32	288,268.15	18,400.09	104,500.00	411,168.24	122,900.09	1.62
0.28	2,067.520	244,881.93	12,888.52	402,762.70	660,533.15	415,651.22	1.00664	yes	0.72	5,316.48	280,366.94	17,895.76	104,500.00	402,762.70	122,395.76	1.65
0.29	2,141.360	251,051.05	13,213.21	394,562.09	658,826.36	407,775.31	1.00925	yes	0.71	5,242.64	272,658.37	17,403.73	104,500.00	394,562.09	121,903.73	1.69
0.30	2,215.200	257,103.11	13,531.74	386,560.10	657,194.95	400,091.84	1.01175	yes	0.70	5,168.80	265,136.49	16,923.61	104,500.00	386,560.10	121,423.61	1.72
0.31	2,289.040	263,042.47	13,844.34	378,750.64	655,637.45	392,594.98	1.01416	yes	0.69	5,094.96	257,795.60	16,455.04	104,500.00	378,750.64	120,955.04	1.76
0.32	2,362.880	268,873.32	14,151.23	371,127.89	654,152.43	385,279.11	1.01646	yes	0.68	5,021.12	250,630.21	15,997.67	104,500.00	371,127.89	120,497.67	1.79
0.33	2,436.720	274,599.72	14,452.62	363,686.23	652,738.56	378,138.84	1.01866	yes	0.67	4,947.28	243,635.05	15,551.17	104,500.00	363,686.23	120,051.17	1.83
0.34	2,510.560	280,225.59	14,748.72	356,420.26	651,394.57	371,168.98	1.02076	yes	0.66	4,873.44	236,805.05	15,115.22	104,500.00	356,420.26	119,615.22	1.87
0.35	2,584.400	285,754.74	15,039.72	349,324.81	650,119.28	364,364.53	1.02277	yes	0.65	4,799.60	230,135.32	14,689.49	104,500.00	349,324.81	119,189.49	1.90
0.36	2,658.240	291,190.85	15,325.83	342,394.87	648,911.55	357,720.70	1.02467	yes	0.64	4,725.76	223,621.18	14,273.69	104,500.00	342,394.87	118,773.69	1.94
0.37	2,732.080	296,537.48	15,607.24	335,625.63	647,770.35	351,232.87	1.02647	yes	0.63	4,651.92	217,258.09	13,867.54	104,500.00	335,625.63	118,367.54	1.98
0.38	2,805.920	301,798.10	15,884.11	329,012.47	646,694.68	344,896.58	1.02818	yes	0.62	4,578.08	211,041.72	13,470.75	104,500.00	329,012.47	117,970.75	2.02
0.39	2,879.760	306,976.06	16,156.63	322,550.91	645,683.61	338,707.55	1.02979	yes	0.61	4,504.24	204,967.86	13,083.05	104,500.00	322,550.91	117,583.05	2.06
0.40	2,953.600	312,074.63	16,424.98	316,236.67	644,736.28	332,661.65	1.03130	yes	0.60	4,430.40	199,032.47	12,704.20	104,500.00	316,236.67	117,204.20	2.10
0.41	3,027.440	317,096.98	16,689.31	310,065.59	643,851.88	326,754.91	1.03272	yes	0.59	4,356.56	193,231.66	12,333.94	104,500.00	310,065.59	116,833.94	2.14
0.42	3,101.280	322,046.20	16,949.80	304,033.68	643,029.68	320,983.48	1.03404	yes	0.58	4,282.72	187,561.66	11,972.02	104,500.00	304,033.68	116,472.02	2.19
0.43	3,175.120	326,925.30	17,206.59	298,137.08	642,268.97	315,343.67	1.03527	yes	0.57	4,208.88	182,018.85	11,618.22	104,500.00	298,137.08	116,118.22	2.23
0.44	3,248.960	331,737.21	17,459.85	292,372.06	641,569.12	309,831.91	1.03640	yes	0.56	4,135.04	176,599.74	11,272.32	104,500.00	292,372.06	115,772.32	2.27
0.45	3,322.800	336,484.79	17,709.73	286,735.04	640,929.55	304,444.76	1.03743	yes	0.55	4,061.20	171,300.93	10,934.10	104,500.00	286,735.04	115,434.10	2.32
0.46	3,396.640	341,170.83	17,956.36	281,222.54	640,349.73	299,178.90	1.03837	yes	0.54	3,987.36	166,119.18	10,603.35	104,500.00	281,222.54	115,103.35	2.36
0.47	3,470.480	345,798.06	18,199.90	275,831.21	639,829.17	294,031.11	1.03921	yes	0.53	3,913.52	161,051.34	10,279.87	104,500.00	275,831.21	114,779.87	2.41
0.48	3,544.320	350,369.16	18,440.48	270,557.81	639,367.45	288,998.30	1.03996	yes	0.52	3,839.68	156,094.35	9,963.47	104,500.00	270,557.81	114,463.47	2.46
0.49	3,618.160	354,886.72	18,678.25	265,399.23	638,964.20	284,077.48	1.04062	yes	0.51	3,765.84	151,245.27	9,653.95	104,500.00	265,399.23	114,153.95	2.51
0.50	3,692.000	359,353.33	18,913.33	260,352.42	638,619.08	279,265.75	1.04118	yes	0.50	3,692.00	146,501.27	9,351.15	104,500.00	260,352.42	113,851.15	2.55
0.51	3,765.840	363,771.47	19,145.87	255,414.46	638,331.80	274,560.33	1.04165	yes	0.49	3,618.16	141,859.59	9,054.87	104,500.00	255,414.46	113,554.87	2.60

TABLE C.4

0.52	3,839.680	368,143.63	19,375.98	250,582.53	638,102.14	269,958.51	1.04203	yes	0.48	3,544.32	137,317.58	8,764.95	104,500.00	250,582.53	113,264.95	2.65
0.53	3,913.520	372,472.22	19,603.80	245,853.88	637,929.90	265,457.68	1.04231	yes	0.47	3,470.48	132,872.65	8,481.23	104,500.00	245,853.88	112,981.23	2.70
0.54	3,987.360	376,759.64	19,829.45	241,225.87	637,814.96	261,055.32	1.04250	yes	0.46	3,396.64	128,522.32	8,203.55	104,500.00	241,225.87	112,703.55	2.76
0.55	4,061.200	381,008.22	20,053.06	236,695.93	637,757.21	256,748.99	1.042590	yes	0.45	3,322.80	124,264.17	7,931.76	104,500.00	236,695.93	112,431.76	2.81
0.56	4,135.040	385,220.28	20,274.75	232,261.57	637,756.60	252,536.32	1.042591	yes	0.44	3,248.96	120,095.87	7,665.69	104,500.00	232,261.57	112,165.69	2.86
0.57	4,208.880	389,398.12	20,494.64	227,920.39	637,813.15	248,415.03	1.04250	yes	0.43	3,175.12	116,015.17	7,405.22	104,500.00	227,920.39	111,905.22	2.92
0.58	4,282.720	393,543.98	20,712.84	223,670.06	637,926.88	244,382.90	1.04231	yes	0.42	3,101.28	112,019.86	7,150.20	104,500.00	223,670.06	111,650.20	2.97
0.59	4,356.560	397,660.10	20,929.48	219,508.32	638,097.90	240,437.80	1.04203	yes	0.41	3,027.44	108,107.82	6,900.50	104,500.00	219,508.32	111,400.50	3.03
0.60	4,430.400	401,748.70	21,144.67	215,432.98	638,326.35	236,577.65	1.04166	yes	0.40	2,953.60	104,277.00	6,655.98	104,500.00	215,432.98	111,155.98	3.09
0.61	4,504.240	405,811.96	21,358.52	211,441.92	638,612.40	232,800.45	1.04119	yes	0.39	2,879.76	100,525.41	6,416.52	104,500.00	211,441.92	110,916.52	3.14
0.62	4,578.080	409,852.06	21,571.16	207,533.08	638,956.30	229,104.24	1.04063	yes	0.38	2,805.92	96,851.10	6,181.99	104,500.00	207,533.08	110,681.99	3.20
0.63	4,651.920	413,871.16	21,782.69	203,704.47	639,358.32	225,487.16	1.03998	yes	0.37	2,732.08	93,252.20	5,952.27	104,500.00	203,704.47	110,452.27	3.26
0.64	4,725.760	417,871.43	21,993.23	199,954.14	639,818.80	221,947.37	1.03923	yes	0.36	2,658.24	89,726.89	5,727.25	104,500.00	199,954.14	110,227.25	3.33
0.65	4,799.600	421,854.99	22,202.89	196,280.22	640,338.11	218,483.11	1.03839	yes	0.35	2,584.40	86,273.40	5,506.81	104,500.00	196,280.22	110,006.81	3.39
0.66	4,873.440	425,824.00	22,411.79	192,680.88	640,916.67	215,092.67	1.03745	yes	0.34	2,510.56	82,890.03	5,290.85	104,500.00	192,680.88	109,790.85	3.45
0.67	4,947.280	429,780.59	22,620.03	189,154.36	641,554.97	211,774.39	1.03642	yes	0.33	2,436.72	79,575.10	5,079.26	104,500.00	189,154.36	109,579.26	3.52
0.68	5,021.120	433,726.89	22,827.73	185,698.93	642,253.54	208,526.66	1.03529	yes	0.32	2,362.88	76,326.99	4,871.94	104,500.00	185,698.93	109,371.94	3.58
0.69	5,094.960	437,665.04	23,035.00	182,312.92	643,012.96	205,347.92	1.03407	yes	0.31	2,289.04	73,144.15	4,668.78	104,500.00	182,312.92	109,168.78	3.65
0.70	5,168.800	441,597.18	23,241.96	178,994.72	643,833.86	202,236.67	1.03275	yes	0.30	2,215.20	70,025.03	4,469.68	104,500.00	178,994.72	108,969.68	3.71
0.71	5,242.640	445,525.48	23,448.71	175,742.74	644,716.93	199,191.45	1.03134	yes	0.29	2,141.36	66,968.18	4,274.56	104,500.00	175,742.74	108,774.56	3.78
0.72	5,316.480	449,452.09	23,655.37	172,555.46	645,662.92	196,210.83	1.02982	yes	0.28	2,067.52	63,972.13	4,083.33	104,500.00	172,555.46	108,583.33	3.85
0.73	5,390.320	453,379.18	23,862.06	169,431.39	646,672.63	193,293.45	1.02822	yes	0.27	1,993.68	61,035.50	3,895.88	104,500.00	169,431.39	108,395.88	3.92
0.74	5,464.160	457,308.96	24,068.89	166,369.07	647,746.93	190,437.96	1.02651	yes	0.26	1,919.84	58,156.93	3,712.14	104,500.00	166,369.07	108,212.14	4.00
0.75	5,538.000	461,243.65	24,275.98	163,367.11	648,886.74	187,643.09	1.02471	yes	0.25	1,846.00	55,335.08	3,532.03	104,500.00	163,367.11	108,032.03	4.07
0.76	5,611.840	465,185.46	24,483.45	160,424.14	650,093.04	184,907.58	1.02281	yes	0.24	1,772.16	52,568.69	3,355.45	104,500.00	160,424.14	107,855.45	4.14
0.77	5,685.680	469,136.68	24,691.40	157,538.82	651,366.90	182,230.22	1.02081	yes	0.23	1,698.32	49,856.49	3,182.33	104,500.00	157,538.82	107,682.33	4.22
0.78	5,759.520	473,099.59	24,899.98	154,709.86	652,709.42	179,609.83	1.01871	yes	0.22	1,624.48	47,197.26	3,012.59	104,500.00	154,709.86	107,512.59	4.30
0.79	5,833.360	477,076.52	25,109.29	151,936.00	654,121.80	177,045.29	1.01651	yes	0.21	1,550.64	44,589.84	2,846.16	104,500.00	151,936.00	107,346.16	4.38
0.80	5,907.200	481,069.83	25,319.46	149,216.01	655,605.30	174,535.48	1.01421	yes	0.20	1,476.80	42,033.05	2,682.96	104,500.00	149,216.01	107,182.96	4.46
0.81	5,981.040	485,081.92	25,530.63	146,548.71	657,161.26	172,079.34	1.01181	yes	0.19	1,402.96	39,525.79	2,522.92	104,500.00	146,548.71	107,022.92	4.54
0.82	6,054.880	489,115.24	25,742.91	143,932.93	658,791.08	169,675.84	1.00930	yes	0.18	1,329.12	37,066.96	2,365.98	104,500.00	143,932.93	106,865.98	4.62
0.83	6,128.720	493,172.29	25,956.44	141,367.54	660,496.27	167,323.98	1.00670	yes	0.17	1,255.28	34,655.49	2,212.05	104,500.00	141,367.54	106,712.05	4.70
0.84	6,202.560	497,255.62	26,171.35	138,851.44	662,278.41	165,022.79	1.00399	yes	0.16	1,181.44	32,290.35	2,061.09	104,500.00	138,851.44	106,561.09	4.79
0.85	6,276.400	501,367.82	26,387.78	136,383.55	664,139.15	162,771.33	1.00117	yes	0.15	1,107.60	29,970.54	1,913.01	104,500.00	136,383.55	106,413.01	4.88
0.86	6,350.240	505,511.55	26,605.87	133,962.84	666,080.26	160,568.71	0.99826	yes	0.14	1,033.76	27,695.07	1,767.77	104,500.00	133,962.84	106,267.77	4.96
0.87	6,424.080	509,689.56	26,825.77	131,588.28	668,103.61	158,414.05	0.99523	yes	0.13	959.92	25,462.98	1,625.30	104,500.00	131,588.28	106,125.30	5.05
0.88	6,497.920	513,904.64	27,047.61	129,258.88	670,211.13	156,306.50	0.99210	yes	0.12	886.08	23,273.35	1,485.53	104,500.00	129,258.88	105,985.53	5.14
0.89	6,571.760	518,159.66	27,271.56	126,973.68	672,404.90	154,245.24	0.98887	yes	0.11	812.24	21,125.26	1,348.42	104,500.00	126,973.68	105,848.42	5.24
0.90	6,645.600	522,457.59	27,497.77	124,731.73	674,687.09	152,229.50	0.98552	no	0.10	738.40	19,017.83	1,213.90	104,500.00	124,731.73	105,713.90	5.33
0.91	6,719.440	526,801.47	27,726.39	122,532.12	677,059.99	150,258.51	0.98207	no	0.09	664.56	16,950.19	1,081.93	104,500.00	122,532.12	105,581.93	5.43
0.92	6,793.280	531,194.45	27,957.60	120,373.94	679,526.00	148,331.55	0.97850	no	0.08	590.72	14,921.51	952.44	104,500.00	120,373.94	105,452.44	5.52
0.93	6,867.120	535,639.76	28,191.57	118,256.34	682,087.66	146,447.90	0.97483	no	0.07	516.88	12,930.96	825.38	104,500.00	118,256.34	105,325.38	5.62
0.94	6,940.960	540,140.75	28,428.46	116,178.45	684,747.65	144,606.91	0.97104	no	0.06	443.04	10,977.74	700.71	104,500.00	116,178.45	105,200.71	5.72
0.95	7,014.800	544,700.88	28,668.47	114,139.44	687,508.79	142,807.91	0.96714	no	0.05	369.20	9,061.07	578.37	104,500.00	114,139.44	105,078.37	5.83
0.96	7,088.640	549,323.75	28,911.78	112,138.51	690,374.03	141,050.28	0.96313	no	0.04	295.36	7,180.20	458.31	104,500.00	112,138.51	104,958.31	5.93
0.97	7,162.480	554,013.07	29,158.58	110,174.86	693,346.51	139,333.44	0.95900	no	0.03	221.52	5,334.37	340.49	104,500.00	110,174.86	104,840.49	6.04
0.98	7,236.320	558,772.69	29,409.09	108,247.72	696,429.51	137,656.81	0.95475	no	0.02	147.68	3,522.86	224.86	104,500.00	108,247.72	104,724.86	6.14
0.99	7,310.160	563,606.64	29,663.51	106,356.35	699,626.50	136,019.86	0.95039	no	0.01	73.84	1,744.97	111.38	104,500.00	106,356.35	104,611.38	6.25

CHART C.5



Mass & F/W
vs
ΔV Fraction for Stage 2a
for Section 3.2.c
mass (kg)
900,000.00
800,000.00
700,000.00
600,000.00
500,000.00
400,000.00
300,000.00
200,000.00
100,000.00
0.00
F/W
5.00000
4.50000
4.00000
3.50000
3.00000
2.50000
2.00000
1.50000
1.00000
0.50000
0.00000
0.00
0.20
0.40
0.60
0.80
1.00
1.20
$\Delta V_{2a\text{-}fract}$
initial mass 2a
propellant mass 2a
F/W-2a
F/W-2b

TABLE C.5

Calculations for Stage 2a & 2b for Section 3.2.c

Isp_2 (s)	455.00
$\Delta V_{2\text{-tot}}$ (m/s)	7,384.00
$m_{i\text{-}2a\text{-allowed}}$ (kg)	673,996.84
$f_{inert\text{-}2a}$	0.08
T_{2a} (N)	8,697,144.00

Isp_2 (s)	455.00
$f_{inert\text{-}2b}$	0.06
$m_{pay\text{-}2b}$ (kg)	104,500.00
T_{2b} (N)	6,522,858.00

$\Delta V_{2a\text{-fract}}$ (m/s)	ΔV_{2a} (m/s)	$m_{prop\text{-}2a}$ (kg)	$m_{inert\text{-}2a}$ (kg)	$m_{pay\text{-}2a}$ (kg)	$m_{i\text{-}2a}$ (kg)	$m_{f\text{-}2a}$ (kg)	F/W_{2a}	$m_{i\text{-allowed}}$ Test	$\Delta V_{2b\text{-fract}}$ (m/s)	ΔV_{2b} (m/s)	$m_{prop\text{-}2b}$ (kg)	$m_{inert\text{-}2b}$ (kg)	$m_{pay\text{-}2a}$ (kg)	$m_{i\text{-}2b}$ (kg)	$m_{f\text{-}2b}$ (kg)	F/W_{2b}
0.01	73.840	12,207.48	1,061.52	730,781.10	744,050.10	731,842.62	1.19153	no	0.99	7,310.16	588,704.23	37,576.87	104,500.00	730,781.10	142,076.87	0.91
0.02	147.680	24,074.19	2,093.41	713,565.52	739,733.12	715,658.93	1.19848	no	0.98	7,236.32	572,521.59	36,543.93	104,500.00	713,565.52	141,043.93	0.93
0.03	221.520	35,615.12	3,096.97	696,874.86	735,586.95	699,971.83	1.20524	no	0.97	7,162.48	556,832.37	35,542.49	104,500.00	696,874.86	140,042.49	0.95
0.04	295.360	46,844.49	4,073.43	680,687.65	731,605.58	684,761.09	1.21180	no	0.96	7,088.64	541,616.39	34,571.26	104,500.00	680,687.65	139,071.26	0.98
0.05	369.200	57,775.80	5,023.98	664,983.57	727,783.35	670,007.55	1.21816	no	0.95	7,014.80	526,854.55	33,629.01	104,500.00	664,983.57	138,129.01	1.00
0.06	443.040	68,421.86	5,949.73	649,743.35	724,114.93	655,693.08	1.22433	no	0.94	6,940.96	512,528.75	32,714.60	104,500.00	649,743.35	137,214.60	1.02
0.07	516.880	78,794.82	6,851.72	634,948.75	720,595.29	641,800.47	1.23031	no	0.93	6,867.12	498,621.82	31,826.92	104,500.00	634,948.75	136,326.92	1.05
0.08	590.720	88,906.28	7,730.98	620,582.43	717,219.69	628,313.41	1.23611	no	0.92	6,793.28	485,117.48	30,964.95	104,500.00	620,582.43	135,464.95	1.07
0.09	664.560	98,767.24	8,588.46	606,627.95	713,983.65	615,216.41	1.24171	no	0.91	6,719.44	472,000.27	30,127.68	104,500.00	606,627.95	134,627.68	1.10
0.10	738.400	108,388.22	9,425.06	593,069.68	710,882.95	602,494.74	1.24712	no	0.90	6,645.60	459,255.50	29,314.18	104,500.00	593,069.68	133,814.18	1.12
0.11	812.240	117,779.21	10,241.67	579,892.75	707,913.63	590,134.42	1.25235	no	0.89	6,571.76	446,869.18	28,523.56	104,500.00	579,892.75	133,023.56	1.15
0.12	886.080	126,949.77	11,039.11	567,083.03	705,071.91	578,122.14	1.25740	no	0.88	6,497.92	434,828.05	27,754.98	104,500.00	567,083.03	132,254.98	1.17
0.13	959.920	135,909.03	11,818.18	554,627.06	702,354.27	566,445.24	1.26227	no	0.87	6,424.08	423,119.44	27,007.62	104,500.00	554,627.06	131,507.62	1.20
0.14	1,033.760	144,665.71	12,579.63	542,512.03	699,757.37	555,091.66	1.26695	no	0.86	6,350.24	411,731.31	26,280.72	104,500.00	542,512.03	130,780.72	1.23
0.15	1,107.600	153,228.16	13,324.19	530,725.71	697,278.05	544,049.90	1.27146	no	0.85	6,276.40	400,652.17	25,573.54	104,500.00	530,725.71	130,073.54	1.25
0.16	1,181.440	161,604.36	14,052.55	519,256.46	694,913.37	533,309.01	1.27578	no	0.84	6,202.56	389,871.07	24,885.39	104,500.00	519,256.46	129,385.39	1.28
0.17	1,255.280	169,801.98	14,765.39	508,093.15	692,660.52	522,858.54	1.27993	no	0.83	6,128.72	379,377.56	24,215.59	104,500.00	508,093.15	128,715.59	1.31
0.18	1,329.120	177,828.37	15,463.34	497,225.17	690,516.88	512,688.51	1.28391	no	0.82	6,054.88	369,161.66	23,563.51	104,500.00	497,225.17	128,063.51	1.34
0.19	1,402.960	185,690.58	16,147.01	486,642.40	688,479.98	502,789.40	1.28770	no	0.81	5,981.04	359,213.85	22,928.54	104,500.00	486,642.40	127,428.54	1.37
0.20	1,476.800	193,395.38	16,816.99	476,335.13	686,547.49	493,152.12	1.29133	no	0.80	5,907.20	349,525.02	22,310.11	104,500.00	476,335.13	126,810.11	1.40
0.21	1,550.640	200,949.29	17,473.85	466,294.10	684,717.24	483,767.95	1.29478	no	0.79	5,833.36	340,086.45	21,707.65	104,500.00	466,294.10	126,207.65	1.43
0.22	1,624.480	208,358.58	18,118.14	456,510.45	682,987.18	474,628.59	1.29806	no	0.78	5,759.52	330,889.83	21,120.63	104,500.00	456,510.45	125,620.63	1.46
0.23	1,698.320	215,629.31	18,750.37	446,975.71	681,355.39	465,726.08	1.30117	no	0.77	5,685.68	321,927.16	20,548.54	104,500.00	446,975.71	125,048.54	1.49
0.24	1,772.160	222,767.29	19,371.07	437,681.73	679,820.09	457,052.80	1.30411	no	0.76	5,611.84	313,190.83	19,990.90	104,500.00	437,681.73	124,490.90	1.52
0.25	1,846.000	229,778.15	19,980.71	428,620.75	678,379.62	448,601.46	1.30688	no	0.75	5,538.00	304,673.51	19,447.25	104,500.00	428,620.75	123,947.25	1.55
0.26	1,919.840	236,667.33	20,579.77	419,785.31	677,032.41	440,365.08	1.30948	no	0.74	5,464.16	296,368.19	18,917.12	104,500.00	419,785.31	123,417.12	1.58
0.27	1,993.680	243,440.08	21,168.70	411,168.24	675,777.03	432,336.95	1.31191	no	0.73	5,390.32	288,268.15	18,400.09	104,500.00	411,168.24	122,900.09	1.62
0.28	2,067.520	250,101.49	21,747.96	402,762.70	674,612.14	424,510.66	1.31418	no	0.72	5,316.48	280,366.94	17,895.76	104,500.00	402,762.70	122,395.76	1.65
0.29	2,141.360	256,656.48	22,317.95	394,562.09	673,536.52	416,880.05	1.31627	yes	0.71	5,242.64	272,658.37	17,403.73	104,500.00	394,562.09	121,903.73	1.69
0.30	2,215.200	263,109.83	22,879.12	386,560.10	672,549.04	409,439.21	1.31821	yes	0.70	5,168.80	265,136.49	16,923.61	104,500.00	386,560.10	121,423.61	1.72
0.31	2,289.040	269,466.19	23,431.84	378,750.64	671,648.67	402,182.48	1.31997	yes	0.69	5,094.96	257,795.60	16,455.04	104,500.00	378,750.64	120,955.04	1.76
0.32	2,362.880	275,730.07	23,976.53	371,127.89	670,834.48	395,104.41	1.32158	yes	0.68	5,021.12	250,630.21	15,997.67	104,500.00	371,127.89	120,497.67	1.79
0.33	2,436.720	281,905.84	24,513.55	363,686.23	670,105.62	388,199.78	1.32301	yes	0.67	4,947.28	243,635.05	15,551.17	104,500.00	363,686.23	120,051.17	1.83
0.34	2,510.560	287,997.80	25,043.29	356,420.26	669,461.35	381,463.55	1.32429	yes	0.66	4,873.44	236,805.05	15,115.22	104,500.00	356,420.26	119,615.22	1.87
0.35	2,584.400	294,010.11	25,566.10	349,324.81	668,901.01	374,890.91	1.32540	yes	0.65	4,799.60	230,135.32	14,689.49	104,500.00	349,324.81	119,189.49	1.90
0.36	2,658.240	299,946.83	26,082.33	342,394.87	668,424.03	368,477.20	1.32634	yes	0.64	4,725.76	223,621.18	14,273.69	104,500.00	342,394.87	118,773.69	1.94
0.37	2,732.080	305,811.94	26,592.34	335,625.63	668,029.92	362,217.97	1.32712	yes	0.63	4,651.92	217,258.09	13,867.54	104,500.00	335,625.63	118,367.54	1.98
0.38	2,805.920	311,609.35	27,096.47	329,012.47	667,718.28	356,108.93	1.32774	yes	0.62	4,578.08	211,041.72	13,470.75	104,500.00	329,012.47	117,970.75	2.02
0.39	2,879.760	317,342.86	27,595.03	322,550.91	667,488.80	350,145.94	1.32820	yes	0.61	4,504.24	204,967.86	13,083.05	104,500.00	322,550.91	117,583.05	2.06
0.40	2,953.600	323,016.21	28,088.37	316,236.67	667,341.25	344,325.04	1.32849	yes	0.60	4,430.40	199,032.47	12,704.20	104,500.00	316,236.67	117,204.20	2.10
0.41	3,027.440	328,633.09	28,576.79	310,065.59	667,275.48	338,642.38	1.32863	yes	0.59	4,356.56	193,231.66	12,333.94	104,500.00	310,065.59	116,833.94	2.14
0.42	3,101.280	334,197.11	29,060.62	304,033.68	667,291.41	333,094.30	1.32859	yes	0.58	4,282.72	187,561.66	11,972.02	104,500.00	304,033.68	116,472.02	2.19
0.43	3,175.120	339,711.84	29,540.16	298,137.08	667,389.07	327,677.24	1.32840	yes	0.57	4,208.88	182,018.85	11,618.22	104,500.00	298,137.08	116,118.22	2.23
0.44	3,248.960	345,180.78	30,015.72	292,372.06	667,568.56	322,387.78	1.32804	yes	0.56	4,135.04	176,599.74	11,272.32	104,500.00	292,372.06	115,772.32	2.27
0.45	3,322.800	350,607.42	30,487.60	286,735.04	667,830.06	317,222.64	1.32752	yes	0.55	4,061.20	171,300.93	10,934.10	104,500.00	286,735.04	115,434.10	2.32
0.46	3,396.640	355,995.18	30,956.10	281,222.54	668,173.82	312,178.64	1.32684	yes	0.54	3,987.36	166,119.18	10,603.35	104,500.00	281,222.54	115,103.35	2.36
0.47	3,470.480	361,347.48	31,421.52	275,831.21	668,600.21	307,252.73	1.32599	yes	0.53	3,913.52	161,051.34	10,279.87	104,500.00	275,831.21	114,779.87	2.41
0.48	3,544.320	366,667.68	31,884.15	270,557.81	669,109.64	302,441.96	1.32498	yes	0.52	3,839.68	156,094.35	9,963.47	104,500.00	270,557.81	114,463.47	2.46
0.49	3,618.160	371,959.15	32,344.27	265,399.23	669,702.65	297,743.50	1.32381	yes	0.51	3,765.84	151,245.27	9,653.95	104,500.00	265,399.23	114,153.95	2.51
0.50	3,692.000	377,225.22	32,802.19	260,352.42	670,379.83	293,154.61	1.32247	yes	0.50	3,692.00	146,501.27	9,351.15	104,500.00	260,352.42	113,851.15	2.55
0.51	3,765.840	382,469.23	33,258.19	255,414.46	671,141.88	288,672.65	1.32097	yes	0.49	3,618.16	141,859.59	9,054.87	104,500.00	255,414.46	113,554.87	2.60

TABLE C.5

0.52	3,839.680	387,694.49	33,712.56	250,582.53	671,989.59	284,295.09	1.31930	yes	0.48	3,544.32	137,317.58	8,764.95	104,500.00	250,582.53	113,264.95	2.65
0.53	3,913.520	392,904.34	34,165.60	245,853.88	672,923.82	280,019.48	1.31747	yes	0.47	3,470.48	132,872.65	8,481.23	104,500.00	245,853.88	112,981.23	2.70
0.54	3,987.360	398,102.11	34,617.57	241,225.87	673,945.55	275,843.44	1.31548	yes	0.46	3,396.64	128,522.32	8,203.55	104,500.00	241,225.87	112,703.55	2.76
0.55	4,061.200	403,291.14	35,068.79	236,695.93	675,055.86	271,764.72	1.313312	no	0.45	3,322.80	124,264.17	7,931.76	104,500.00	236,695.93	112,431.76	2.81
0.56	4,135.040	408,474.77	35,519.55	232,261.57	676,255.89	267,781.11	1.310982	no	0.44	3,248.96	120,095.87	7,665.69	104,500.00	232,261.57	112,165.69	2.86
0.57	4,208.880	413,656.41	35,970.12	227,920.39	677,546.92	263,890.51	1.30848	no	0.43	3,175.12	116,015.17	7,405.22	104,500.00	227,920.39	111,905.22	2.92
0.58	4,282.720	418,839.45	36,420.82	223,670.06	678,930.34	260,090.88	1.30582	no	0.42	3,101.28	112,019.86	7,150.20	104,500.00	223,670.06	111,650.20	2.97
0.59	4,356.560	424,027.34	36,871.94	219,508.32	680,407.61	256,380.27	1.30298	no	0.41	3,027.44	108,107.82	6,900.50	104,500.00	219,508.32	111,400.50	3.03
0.60	4,430.400	429,223.57	37,323.79	215,432.98	681,980.34	252,756.77	1.29998	no	0.40	2,953.60	104,277.00	6,655.98	104,500.00	215,432.98	111,155.98	3.09
0.61	4,504.240	434,431.65	37,776.67	211,441.92	683,650.24	249,218.59	1.29680	no	0.39	2,879.76	100,525.41	6,416.52	104,500.00	211,441.92	110,916.52	3.14
0.62	4,578.080	439,655.18	38,230.89	207,533.08	685,419.15	245,763.97	1.29346	no	0.38	2,805.92	96,851.10	6,181.99	104,500.00	207,533.08	110,681.99	3.20
0.63	4,651.920	444,897.80	38,686.77	203,704.47	687,289.03	242,391.23	1.28994	no	0.37	2,732.08	93,252.20	5,952.27	104,500.00	203,704.47	110,452.27	3.26
0.64	4,725.760	450,163.22	39,144.63	199,954.14	689,261.98	239,098.77	1.28624	no	0.36	2,658.24	89,726.89	5,727.25	104,500.00	199,954.14	110,227.25	3.33
0.65	4,799.600	455,455.22	39,604.80	196,280.22	691,340.24	235,885.02	1.28238	no	0.35	2,584.40	86,273.40	5,506.81	104,500.00	196,280.22	110,006.81	3.39
0.66	4,873.440	460,777.67	40,067.62	192,680.88	693,526.17	232,748.50	1.27834	no	0.34	2,510.56	82,890.03	5,290.85	104,500.00	192,680.88	109,790.85	3.45
0.67	4,947.280	466,134.53	40,533.44	189,154.36	695,822.33	229,687.79	1.27412	no	0.33	2,436.72	79,575.10	5,079.26	104,500.00	189,154.36	109,579.26	3.52
0.68	5,021.120	471,529.86	41,002.60	185,698.93	698,231.38	226,701.52	1.26972	no	0.32	2,362.88	76,326.99	4,871.94	104,500.00	185,698.93	109,371.94	3.58
0.69	5,094.960	476,967.82	41,475.46	182,312.92	700,756.20	223,788.38	1.26515	no	0.31	2,289.04	73,144.15	4,668.78	104,500.00	182,312.92	109,168.78	3.65
0.70	5,168.800	482,452.69	41,952.41	178,994.72	703,399.82	220,947.13	1.26039	no	0.30	2,215.20	70,025.03	4,469.68	104,500.00	178,994.72	108,969.68	3.71
0.71	5,242.640	487,988.89	42,433.82	175,742.74	706,165.45	218,176.56	1.25546	no	0.29	2,141.36	66,968.18	4,274.56	104,500.00	175,742.74	108,774.56	3.78
0.72	5,316.480	493,580.97	42,920.08	172,555.46	709,056.51	215,475.54	1.25034	no	0.28	2,067.52	63,972.13	4,083.33	104,500.00	172,555.46	108,583.33	3.85
0.73	5,390.320	499,233.62	43,411.62	169,431.39	712,076.62	212,843.00	1.24503	no	0.27	1,993.68	61,035.50	3,895.88	104,500.00	169,431.39	108,395.88	3.92
0.74	5,464.160	504,951.71	43,908.84	166,369.07	715,229.63	210,277.92	1.23954	no	0.26	1,919.84	58,156.93	3,712.14	104,500.00	166,369.07	108,212.14	4.00
0.75	5,538.000	510,740.28	44,412.20	163,367.11	718,519.59	207,779.31	1.23387	no	0.25	1,846.00	55,335.08	3,532.03	104,500.00	163,367.11	108,032.03	4.07
0.76	5,611.840	516,604.56	44,922.14	160,424.14	721,950.84	205,346.27	1.22800	no	0.24	1,772.16	52,568.69	3,355.45	104,500.00	160,424.14	107,855.45	4.14
0.77	5,685.680	522,549.99	45,439.13	157,538.82	725,527.93	202,977.95	1.22195	no	0.23	1,698.32	49,856.49	3,182.33	104,500.00	157,538.82	107,682.33	4.22
0.78	5,759.520	528,582.21	45,963.67	154,709.86	729,255.73	200,673.53	1.21570	no	0.22	1,624.48	47,197.26	3,012.59	104,500.00	154,709.86	107,512.59	4.30
0.79	5,833.360	534,707.12	46,496.27	151,936.00	733,139.38	198,432.27	1.20926	no	0.21	1,550.64	44,589.84	2,846.16	104,500.00	151,936.00	107,346.16	4.38
0.80	5,907.200	540,930.87	47,037.47	149,216.01	737,184.35	196,253.48	1.20263	no	0.20	1,476.80	42,033.05	2,682.96	104,500.00	149,216.01	107,182.96	4.46
0.81	5,981.040	547,259.89	47,587.82	146,548.71	741,396.42	194,136.53	1.19580	no	0.19	1,402.96	39,525.79	2,522.92	104,500.00	146,548.71	107,022.92	4.54
0.82	6,054.880	553,700.90	48,147.90	143,932.93	745,781.74	192,080.84	1.18876	no	0.18	1,329.12	37,066.96	2,365.98	104,500.00	143,932.93	106,865.98	4.62
0.83	6,128.720	560,260.96	48,718.34	141,367.54	750,346.85	190,085.89	1.18153	no	0.17	1,255.28	34,655.49	2,212.05	104,500.00	141,367.54	106,712.05	4.70
0.84	6,202.560	566,947.46	49,299.78	138,851.44	755,098.68	188,151.22	1.17410	no	0.16	1,181.44	32,290.35	2,061.09	104,500.00	138,851.44	106,561.09	4.79
0.85	6,276.400	573,768.18	49,892.88	136,383.55	760,044.61	186,276.44	1.16646	no	0.15	1,107.60	29,970.54	1,913.01	104,500.00	136,383.55	106,413.01	4.88
0.86	6,350.240	580,731.29	50,498.37	133,962.84	765,192.50	184,461.21	1.15861	no	0.14	1,033.76	27,695.07	1,767.77	104,500.00	133,962.84	106,267.77	4.96
0.87	6,424.080	587,845.41	51,116.99	131,588.28	770,550.68	182,705.27	1.15055	no	0.13	959.92	25,462.98	1,625.30	104,500.00	131,588.28	106,125.30	5.05
0.88	6,497.920	595,119.64	51,749.53	129,258.88	776,128.05	181,008.42	1.14228	no	0.12	886.08	23,273.35	1,485.53	104,500.00	129,258.88	105,985.53	5.14
0.89	6,571.760	602,563.58	52,396.83	126,973.68	781,934.09	179,370.51	1.13380	no	0.11	812.24	21,125.26	1,348.42	104,500.00	126,973.68	105,848.42	5.24
0.90	6,645.600	610,187.39	53,059.77	124,731.73	787,978.90	177,791.51	1.12511	no	0.10	738.40	19,017.83	1,213.90	104,500.00	124,731.73	105,713.90	5.33
0.91	6,719.440	618,001.85	53,739.29	122,532.12	794,273.26	176,271.41	1.11619	no	0.09	664.56	16,950.19	1,081.93	104,500.00	122,532.12	105,581.93	5.43
0.92	6,793.280	626,018.38	54,436.38	120,373.94	800,828.70	174,810.33	1.10705	no	0.08	590.72	14,921.51	952.44	104,500.00	120,373.94	105,452.44	5.52
0.93	6,867.120	634,249.10	55,152.10	118,256.34	807,657.53	173,408.43	1.09769	no	0.07	516.88	12,930.96	825.38	104,500.00	118,256.34	105,325.38	5.62
0.94	6,940.960	642,706.92	55,887.56	116,178.45	814,772.93	172,066.00	1.08811	no	0.06	443.04	10,977.74	700.71	104,500.00	116,178.45	105,200.71	5.72
0.95	7,014.800	651,405.61	56,643.97	114,139.44	822,189.01	170,783.40	1.07829	no	0.05	369.20	9,061.07	578.37	104,500.00	114,139.44	105,078.37	5.83
0.96	7,088.640	660,359.81	57,422.59	112,138.51	829,920.91	169,561.10	1.06825	no	0.04	295.36	7,180.20	458.31	104,500.00	112,138.51	104,958.31	5.93
0.97	7,162.480	669,585.21	58,224.80	110,174.86	837,984.87	168,399.66	1.05797	no	0.03	221.52	5,334.37	340.49	104,500.00	110,174.86	104,840.49	6.04
0.98	7,236.320	679,098.57	59,052.05	108,247.72	846,398.34	167,299.77	1.04745	no	0.02	147.68	3,522.86	224.86	104,500.00	108,247.72	104,724.86	6.14
0.99	7,310.160	688,917.86	59,905.90	106,356.35	855,180.11	166,262.25	1.03669	no	0.01	73.84	1,744.97	111.38	104,500.00	106,356.35	104,611.38	6.25

TABLE C.6

$\text{Pressure}_{\text{Initial}}$ Test for Helium Section 3.2.c-stage 2a

gamma	1.66		
R (J/kg-K)	2,078.00	Critical Temp (K)	126.20
p_{needed} (Pa)	55,433,849	**Tank Factor**	**50,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	259.64		
Vol_{LH} (m^3)	696.04		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{Initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	$State_{final}$ Test
8,278	9,233	9,695	298	1.30	72,064,004	268	963,302	8,278	1,216,145	0.00	GAS
6,773	7,729	8,115	298	1.35	74,835,696	264	818,504	6,773	1,033,340	0.00	GAS
5,744	6,700	7,035	298	1.40	77,607,389	261	719,871	5,744	908,819	0.00	GAS
4,996	5,951	6,249	298	1.45	80,379,081	257	648,459	4,996	818,663	0.00	GAS
4,427	5,383	5,652	298	1.50	83,150,774	254	594,441	4,427	750,467	0.00	GAS
3,980	4,935	5,182	298	1.55	85,922,466	250	552,210	3,980	697,151	0.00	GAS
3,619	4,575	4,803	298	1.60	88,694,158	247	518,333	3,619	654,383	0.00	GAS
3,321	4,277	4,491	298	1.65	91,465,851	244	490,594	3,321	619,362	0.00	GAS
3,072	4,028	4,229	298	1.70	94,237,543	241	467,493	3,072	590,199	0.00	GAS
2,860	3,815	4,006	298	1.75	97,009,236	239	447,985	2,860	565,569	0.00	GAS
2,677	3,632	3,814	298	1.80	99,780,928	236	431,313	2,677	544,522	0.00	GAS
2,517	3,473	3,647	298	1.85	102,552,621	233	416,921	2,517	526,353	0.00	GAS
2,378	3,333	3,500	298	1.90	105,324,313	231	404,389	2,378	510,531	0.00	GAS
2,254	3,209	3,370	298	1.95	108,096,006	229	393,391	2,254	496,647	0.00	GAS
2,143	3,099	3,254	298	2.00	110,867,698	226	383,677	2,143	484,383	0.00	GAS
2,044	2,999	3,149	298	2.05	113,639,390	224	375,045	2,044	473,485	0.00	GAS
1,954	2,910	3,055	298	2.10	116,411,083	222	367,335	1,954	463,751	0.00	GAS
1,873	2,828	2,970	298	2.15	119,182,775	220	360,415	1,873	455,015	0.00	GAS
1,798	2,754	2,892	298	2.20	121,954,468	218	354,179	1,798	447,143	0.00	GAS
1,730	2,686	2,820	298	2.25	124,726,160	216	348,539	1,730	440,022	0.00	GAS
1,668	2,624	2,755	298	2.30	127,497,853	214	343,419	1,668	433,558	0.00	GAS
1,610	2,566	2,694	298	2.35	130,269,545	212	338,758	1,610	427,673	0.00	GAS
1,557	2,513	2,638	298	2.40	133,041,238	210	334,502	1,557	422,300	0.00	GAS
1,507	2,463	2,586	298	2.45	135,812,930	209	330,607	1,507	417,383	0.00	GAS
1,461	2,417	2,538	298	2.50	138,584,623	207	327,033	1,461	412,871	0.00	GAS
1,418	2,374	2,493	298	2.55	141,356,315	205	323,748	1,418	408,723	0.00	GAS
1,378	2,334	2,450	298	2.60	144,128,007	204	320,722	1,378	404,903	0.00	GAS
1,340	2,296	2,411	298	2.65	146,899,700	202	317,930	1,340	401,378	0.00	GAS
1,305	2,260	2,373	298	2.70	149,671,392	201	315,349	1,305	398,121	0.00	GAS
1,271	2,227	2,338	298	2.75	152,443,085	199	312,962	1,271	395,106	0.00	GAS
1,240	2,195	2,305	298	2.80	155,214,777	198	310,749	1,240	392,313	0.00	GAS
1,210	2,166	2,274	298	2.85	157,986,470	197	308,696	1,210	389,721	0.00	GAS
1,182	2,137	2,244	298	2.90	160,758,162	195	306,790	1,182	387,315	0.00	GAS
1,155	2,111	2,216	298	2.95	163,529,855	194	305,018	1,155	385,078	0.00	GAS
1,130	2,085	2,190	298	3.00	166,301,547	193	303,370	1,130	382,997	0.00	GAS
1,105	2,061	2,164	298	3.05	169,073,239	191	301,835	1,105	381,059	0.00	GAS
1,083	2,038	2,140	298	3.10	171,844,932	190	300,405	1,083	379,254	0.00	GAS
1,061	2,016	2,117	298	3.15	174,616,624	189	299,073	1,061	377,572	0.00	GAS
1,040	1,995	2,095	298	3.20	177,388,317	188	297,831	1,040	376,004	0.00	GAS
1,020	1,975	2,074	298	3.25	180,160,009	187	296,672	1,020	374,541	0.00	GAS
1,001	1,956	2,054	298	3.30	182,931,702	185	295,591	1,001	373,176	0.00	GAS
982	1,938	2,035	298	3.35	185,703,394	184	294,582	982	371,902	0.00	GAS
965	1,920	2,016	298	3.40	188,475,087	183	293,640	965	370,714	0.00	GAS
948	1,904	1,999	298	3.45	191,246,779	182	292,762	948	369,605	0.00	GAS
932	1,887	1,982	298	3.50	194,018,472	181	291,942	932	368,570	0.00	GAS
916	1,872	1,966	298	3.55	196,790,164	180	291,178	916	367,605	0.00	GAS
901	1,857	1,950	298	3.60	199,561,856	179	290,465	901	366,705	0.00	GAS
887	1,843	1,935	298	3.65	202,333,549	178	289,801	887	365,866	0.00	GAS
873	1,829	1,920	298	3.70	205,105,241	177	289,182	873	365,085	0.00	GAS
860	1,815	1,906	298	3.75	207,876,934	176	288,606	860	364,358	0.00	GAS
847	1,803	1,893	298	3.80	210,648,626	175	288,070	847	363,682	0.00	GAS
834	1,790	1,880	298	3.85	213,420,319	174	287,573	834	363,053	0.00	GAS
822	1,778	1,867	298	3.90	216,192,011	173	287,111	822	362,470	0.00	GAS

TABLE C.6

811	1,766	1,855	298	3.95	218,963,704	173	286,683	811	361,930	0.00	GAS
800	1,755	1,843	298	4.00	221,735,396	172	286,287	800	361,430	0.00	GAS
789	1,744	1,832	298	4.05	224,507,088	171	285,921	789	360,968	0.00	GAS
778	1,734	1,820	298	4.10	227,278,781	170	285,583	778	360,542	0.00	GAS
768	1,724	1,810	298	4.15	230,050,473	169	285,273	768	360,150	0.00	GAS
758	1,714	1,799	298	4.20	232,822,166	168	284,989	758	359,791	0.00	GAS
748	1,704	1,789	298	4.25	235,593,858	168	284,729	748	359,463	0.00	GAS
739	1,695	1,779	298	4.30	238,365,551	167	284,492	739	359,163	0.00	GAS
730	1,686	1,770	298	4.35	241,137,243	166	284,276	730	358,892	0.00	GAS
721	1,677	1,761	298	4.40	243,908,936	165	284,082	721	358,647	0.00	GAS
713	1,668	1,752	298	4.45	246,680,628	165	283,908	713	358,427	0.00	GAS
704	1,660	1,743	298	4.50	249,452,321	164	283,752	704	358,230	0.00	GAS
696	1,652	1,735	298	4.55	252,224,013	163	283,615	696	358,057	0.00	GAS
688	1,644	1,726	298	4.60	254,995,705	162	283,494	688	357,905	0.00	GAS
681	1,636	1,718	298	4.65	257,767,398	162	283,390	681	357,773	0.00	GAS
673	1,629	1,710	298	4.70	260,539,090	161	283,302	673	357,662	0.00	GAS
666	1,622	1,703	298	4.75	263,310,783	160	283,228	666	357,569	0.00	GAS
659	1,615	1,695	298	4.80	266,082,475	160	283,169	659	357,494	0.00	GAS
652	1,608	1,688	298	4.85	268,854,168	159	283,123	652	357,436	0.00	GAS
645	1,601	1,681	298	4.90	271,625,860	158	283,090	645	357,394	0.00	GAS
639	1,594	1,674	298	4.95	274,397,553	158	283,070	639	357,368	0.00	GAS
632	[illegible]	[illegible]	298	5.00	277,169,245	157	283,061	632	357,357	0.00	GAS
626	1,582	1,661	298	5.05	279,940,937	157	283,063	626	357,361	0.00	GAS
620	1,576	1,655	298	5.10	282,712,630	156	283,077	620	357,378	0.00	GAS
614	1,570	1,648	298	5.15	285,484,322	155	283,101	614	357,408	0.00	GAS
608	1,564	1,642	298	5.20	288,256,015	155	283,135	608	357,450	0.00	GAS
603	1,558	1,636	298	5.25	291,027,707	154	283,178	603	357,505	0.00	GAS
597	1,553	1,630	298	5.30	293,799,400	154	283,230	597	357,571	0.00	GAS
592	1,547	1,625	298	5.35	296,571,092	153	283,292	592	357,648	0.00	GAS
586	1,542	1,619	298	5.40	299,342,785	152	283,361	586	357,736	0.00	GAS
581	1,537	1,613	298	5.45	302,114,477	152	283,439	581	357,834	0.00	GAS
576	1,532	1,608	298	5.50	304,886,169	151	283,524	576	357,942	0.00	GAS
571	1,527	1,603	298	5.55	307,657,862	151	283,617	571	358,059	0.00	GAS
566	1,522	1,598	298	5.60	310,429,554	150	283,717	566	358,186	0.00	GAS
561	1,517	1,593	298	5.65	313,201,247	150	283,824	561	358,321	0.00	GAS
556	1,512	1,588	298	5.70	315,972,939	149	283,937	556	358,464	0.00	GAS
552	1,508	1,583	298	5.75	318,744,632	149	284,057	552	358,615	0.00	GAS
547	1,503	1,578	298	5.80	321,516,324	148	284,183	547	358,774	0.00	GAS
543	1,499	1,574	298	5.85	324,288,017	148	284,315	543	358,940	0.00	GAS
539	1,494	1,569	298	5.90	327,059,709	147	284,452	539	359,113	0.00	GAS
534	1,490	1,564	298	5.95	329,831,402	147	284,595	534	359,294	0.00	GAS
530	1,486	1,560	298	6.00	332,603,094	146	284,743	530	359,480	0.00	GAS
526	1,482	1,556	298	6.05	335,374,786	146	284,896	526	359,674	0.00	GAS
522	1,478	1,552	298	6.10	338,146,479	145	285,053	522	359,873	0.00	GAS
518	1,474	1,547	298	6.15	340,918,171	145	285,216	518	360,078	0.00	GAS
514	1,470	1,543	298	6.20	343,689,864	144	285,383	514	360,289	0.00	GAS
510	1,466	1,539	298	6.25	346,461,556	144	285,554	510	360,505	0.00	GAS
507	1,462	1,535	298	6.30	349,233,249	143	285,729	507	360,726	0.00	GAS
503	1,459	1,532	298	6.35	352,004,941	143	285,909	503	360,953	0.00	GAS
499	1,455	1,528	298	6.40	354,776,634	142	286,092	499	361,184	0.00	GAS
496	1,451	1,524	298	6.45	357,548,326	142	286,279	496	361,420	0.00	GAS
492	1,448	1,520	298	6.50	360,320,018	142	286,469	492	361,660	0.00	GAS
489	1,445	1,517	298	6.55	363,091,711	141	286,663	489	361,905	0.00	GAS
486	1,441	1,513	298	6.60	365,863,403	141	286,861	486	362,154	0.00	GAS
482	1,438	1,510	298	6.65	368,635,096	140	287,061	482	362,408	0.00	GAS
479	1,435	1,506	298	6.70	371,406,788	140	287,265	479	362,665	0.00	GAS
476	1,431	1,503	298	6.75	374,178,481	139	287,471	476	362,925	0.00	GAS
473	1,428	1,500	298	6.80	376,950,173	139	287,681	473	363,190	0.00	GAS
469	1,425	1,496	298	6.85	379,721,866	139	287,893	469	363,458	0.00	GAS
466	1,422	1,493	298	6.90	382,493,558	138	288,108	466	363,729	0.00	GAS
463	1,419	1,490	298	6.95	385,265,251	138	288,326	463	364,004	0.00	GAS
460	1,416	1,487	298	7.00	388,036,943	137	288,546	460	364,282	0.00	GAS
458	1,413	1,484	298	7.05	390,808,635	137	288,768	458	364,562	0.00	GAS

TABLE C.7

$Pressure_{initial}$ Test for Helium Section 3.2.c-stage 2b

gamma	1.66		
R (J/kg-K)	2,078.00	Critical Temp (K)	126.20
p_{needed} (Pa)	55,433,849	**Tank Factor**	**50,000**
p_{final} (Pa)	55,433,849		
Vol_{OX} (m^3)	152.67		
Vol_{LH} (m^3)	409.26		

Tank Volume (m^3)	Vol Pressurant (m^3)	Vol w/ 5% margin (m^3)	Temp init (K)	increase factor	$p_{initial}$ (Pa)	temp fin (K)	mass pressurant (kg)	Volume press req (gas law), (m^3)	m_{tank} (kg)	diff in volume req	$State_{final}$ Test
4,867	5,429	5,701	298	1.30	72,064,004	268	566,408	4,867	715,076	0.00	GAS
3,982	4,544	4,771	298	1.35	74,835,696	264	481,269	3,982	607,590	0.00	GAS
3,377	3,939	4,136	298	1.40	77,607,389	261	423,274	3,377	534,373	0.00	GAS
2,937	3,499	3,674	298	1.45	80,379,081	257	381,285	2,937	481,363	0.00	GAS
2,603	3,165	3,323	298	1.50	83,150,774	254	349,523	2,603	441,264	0.00	GAS
2,340	2,902	3,047	298	1.55	85,922,466	250	324,691	2,340	409,915	0.00	GAS
2,128	2,690	2,824	298	1.60	88,694,158	247	304,773	2,128	384,768	0.00	GAS
1,953	2,515	2,641	298	1.65	91,465,851	244	288,462	1,953	364,176	0.00	GAS
1,806	2,368	2,487	298	1.70	94,237,543	241	274,879	1,806	347,028	0.00	GAS
1,681	2,243	2,356	298	1.75	97,009,236	239	263,409	1,681	332,547	0.00	GAS
1,574	2,136	2,243	298	1.80	99,780,928	236	253,606	1,574	320,171	0.00	GAS
1,480	2,042	2,144	298	1.85	102,552,621	233	245,144	1,480	309,488	0.00	GAS
1,398	1,960	2,058	298	1.90	105,324,313	231	237,775	1,398	300,185	0.00	GAS
1,325	1,887	1,981	298	1.95	108,096,006	229	231,309	1,325	292,021	0.00	GAS
1,260	1,822	1,913	298	2.00	110,867,698	226	225,597	1,260	284,810	0.00	GAS
1,202	1,764	1,852	298	2.05	113,639,390	224	220,521	1,202	278,402	0.00	GAS
1,149	1,711	1,796	298	2.10	116,411,083	222	215,988	1,149	272,679	0.00	GAS
1,101	1,663	1,746	298	2.15	119,182,775	220	211,919	1,101	267,543	0.00	GAS
1,057	1,619	1,700	298	2.20	121,954,468	218	208,253	1,057	262,914	0.00	GAS
1,017	1,579	1,658	298	2.25	124,726,160	216	204,936	1,017	258,726	0.00	GAS
981	1,543	1,620	298	2.30	127,497,853	214	201,926	981	254,926	0.00	GAS
947	1,509	1,584	298	2.35	130,269,545	212	199,185	947	251,466	0.00	GAS
915	1,477	1,551	298	2.40	133,041,238	210	196,682	915	248,307	0.00	GAS
886	1,448	1,521	298	2.45	135,812,930	209	194,392	886	245,415	0.00	GAS
859	1,421	1,492	298	2.50	138,584,623	207	192,291	859	242,762	0.00	GAS
834	1,396	1,466	298	2.55	141,356,315	205	190,359	834	240,324	0.00	GAS
810	1,372	1,441	298	2.60	144,128,007	204	188,580	810	238,077	0.00	GAS
788	1,350	1,417	298	2.65	146,899,700	202	186,938	788	236,005	0.00	GAS
767	1,329	1,396	298	2.70	149,671,392	201	185,421	767	234,089	0.00	GAS
748	1,309	1,375	298	2.75	152,443,085	199	184,017	748	232,317	0.00	GAS
729	1,291	1,355	298	2.80	155,214,777	198	182,716	729	230,674	0.00	GAS
711	1,273	1,337	298	2.85	157,986,470	197	181,509	711	229,151	0.00	GAS
695	1,257	1,320	298	2.90	160,758,162	195	180,388	695	227,736	0.00	GAS
679	1,241	1,303	298	2.95	163,529,855	194	179,346	679	226,420	0.00	GAS
664	1,226	1,287	298	3.00	166,301,547	193	178,377	664	225,197	0.00	GAS
650	1,212	1,273	298	3.05	169,073,239	191	177,475	650	224,057	0.00	GAS
637	1,198	1,258	298	3.10	171,844,932	190	176,634	637	222,996	0.00	GAS
624	1,186	1,245	298	3.15	174,616,624	189	175,851	624	222,007	0.00	GAS
611	1,173	1,232	298	3.20	177,388,317	188	175,120	611	221,085	0.00	GAS
600	1,162	1,220	298	3.25	180,160,009	187	174,439	600	220,225	0.00	GAS
588	1,150	1,208	298	3.30	182,931,702	185	173,803	588	219,422	0.00	GAS
578	1,140	1,196	298	3.35	185,703,394	184	173,210	578	218,673	0.00	GAS
567	1,129	1,186	298	3.40	188,475,087	183	172,656	567	217,974	0.00	GAS
557	1,119	1,175	298	3.45	191,246,779	182	172,140	557	217,322	0.00	GAS
548	1,110	1,165	298	3.50	194,018,472	181	171,658	548	216,714	0.00	GAS
539	1,101	1,156	298	3.55	196,790,164	180	171,209	539	216,146	0.00	GAS
530	1,092	1,146	298	3.60	199,561,856	179	170,789	530	215,617	0.00	GAS
522	1,083	1,138	298	3.65	202,333,549	178	170,399	522	215,124	0.00	GAS
513	1,075	1,129	298	3.70	205,105,241	177	170,035	513	214,665	0.00	GAS
506	1,067	1,121	298	3.75	207,876,934	176	169,696	506	214,237	0.00	GAS
498	1,060	1,113	298	3.80	210,648,626	175	169,381	498	213,840	0.00	GAS
491	1,053	1,105	298	3.85	213,420,319	174	169,089	491	213,470	0.00	GAS
484	1,045	1,098	298	3.90	216,192,011	173	168,817	484	213,127	0.00	GAS

TABLE C.7

477	1,039	1,091	298	3.95	218,963,704	173	168,565	477	212,810	0.00 GAS
470	1,032	1,084	298	4.00	221,735,396	172	168,333	470	212,516	0.00 GAS
464	1,026	1,077	298	4.05	224,507,088	171	168,117	464	212,244	0.00 GAS
458	1,019	1,070	298	4.10	227,278,781	170	167,919	458	211,994	0.00 GAS
452	1,013	1,064	298	4.15	230,050,473	169	167,737	452	211,763	0.00 GAS
446	1,008	1,058	298	4.20	232,822,166	168	167,569	446	211,552	0.00 GAS
440	1,002	1,052	298	4.25	235,593,858	168	167,416	440	211,359	0.00 GAS
435	996	1,046	298	4.30	238,365,551	167	167,277	435	211,183	0.00 GAS
429	991	1,041	298	4.35	241,137,243	166	167,151	429	211,023	0.00 GAS
424	986	1,035	298	4.40	243,908,936	165	167,036	424	210,879	0.00 GAS
419	981	1,030	298	4.45	246,680,628	165	166,934	419	210,750	0.00 GAS
414	976	1,025	298	4.50	249,452,321	164	166,842	414	210,634	0.00 GAS
409	971	1,020	298	4.55	252,224,013	163	166,762	409	210,532	0.00 GAS
405	967	1,015	298	4.60	254,995,705	162	166,691	405	210,443	0.00 GAS
400	962	1,010	298	4.65	257,767,398	162	166,630	400	210,366	0.00 GAS
396	958	1,006	298	4.70	260,539,090	161	166,578	396	210,300	0.00 GAS
392	954	1,001	298	4.75	263,310,783	160	166,534	392	210,245	0.00 GAS
387	949	997	298	4.80	266,082,475	160	166,499	387	210,201	0.00 GAS
383	945	993	298	4.85	268,854,168	159	166,472	383	210,167	0.00 GAS
379	941	988	298	4.90	271,625,860	158	166,453	379	210,143	0.00 GAS
376	938	984	298	4.95	274,397,553	158	166,441	376	210,127	0.00 GAS
[redacted]						157	166,436	372	210,121	0.00 GAS
368	930	977	298	5.05	279,940,937	157	166,437	368	210,123	0.00 GAS
365	927	973	298	5.10	282,712,630	156	166,445	365	210,133	0.00 GAS
361	923	969	298	5.15	285,484,322	155	166,459	361	210,151	0.00 GAS
358	920	966	298	5.20	288,256,015	155	166,479	358	210,176	0.00 GAS
354	916	962	298	5.25	291,027,707	154	166,505	354	210,208	0.00 GAS
351	913	959	298	5.30	293,799,400	154	166,535	351	210,247	0.00 GAS
348	910	955	298	5.35	296,571,092	153	166,571	348	210,292	0.00 GAS
345	907	952	298	5.40	299,342,785	152	166,612	345	210,344	0.00 GAS
342	904	949	298	5.45	302,114,477	152	166,658	342	210,402	0.00 GAS
339	901	946	298	5.50	304,886,169	151	166,708	339	210,465	0.00 GAS
336	898	942	298	5.55	307,657,862	151	166,763	336	210,534	0.00 GAS
333	895	939	298	5.60	310,429,554	150	166,822	333	210,608	0.00 GAS
330	892	936	298	5.65	313,201,247	150	166,884	330	210,687	0.00 GAS
327	889	934	298	5.70	315,972,939	149	166,951	327	210,772	0.00 GAS
324	886	931	298	5.75	318,744,632	149	167,022	324	210,861	0.00 GAS
322	884	928	298	5.80	321,516,324	148	167,096	322	210,954	0.00 GAS
319	881	925	298	5.85	324,288,017	148	167,173	319	211,052	0.00 GAS
317	879	923	298	5.90	327,059,709	147	167,254	317	211,154	0.00 GAS
314	876	920	298	5.95	329,831,402	147	167,338	314	211,260	0.00 GAS
312	874	917	298	6.00	332,603,094	146	167,425	312	211,369	0.00 GAS
309	871	915	298	6.05	335,374,786	146	167,515	309	211,483	0.00 GAS
307	869	912	298	6.10	338,146,479	145	167,607	307	211,600	0.00 GAS
305	867	910	298	6.15	340,918,171	145	167,703	305	211,721	0.00 GAS
302	864	907	298	6.20	343,689,864	144	167,801	302	211,845	0.00 GAS
300	862	905	298	6.25	346,461,556	144	167,902	300	211,972	0.00 GAS
298	860	903	298	6.30	349,233,249	143	168,005	298	212,102	0.00 GAS
296	858	901	298	6.35	352,004,941	143	168,110	296	212,235	0.00 GAS
294	856	898	298	6.40	354,776,634	142	168,218	294	212,371	0.00 GAS
292	853	896	298	6.45	357,548,326	142	168,328	292	212,510	0.00 GAS
289	851	894	298	6.50	360,320,018	142	168,440	289	212,651	0.00 GAS
287	849	892	298	6.55	363,091,711	141	168,554	287	212,795	0.00 GAS
285	847	890	298	6.60	365,863,403	141	168,670	285	212,942	0.00 GAS
284	845	888	298	6.65	368,635,096	140	168,788	284	213,091	0.00 GAS
282	844	886	298	6.70	371,406,788	140	168,908	282	213,242	0.00 GAS
280	842	884	298	6.75	374,178,481	139	169,029	280	213,395	0.00 GAS
278	840	882	298	6.80	376,950,173	139	169,152	278	213,551	0.00 GAS
276	838	880	298	6.85	379,721,866	139	169,277	276	213,708	0.00 GAS
274	836	878	298	6.90	382,493,558	138	169,403	274	213,868	0.00 GAS
272	834	876	298	6.95	385,265,251	138	169,531	272	214,029	0.00 GAS
271	833	874	298	7.00	388,036,943	137	169,661	271	214,192	0.00 GAS
269	831	873	298	7.05	390,808,635	137	169,791	269	214,358	0.00 GAS

TABLE C.8

ΔV & T/W Calculations
Section 3.2.c

Stage 1

ET 2a&2b	
$m_{tank\text{-}LH\text{-}tot}$ (kg)	839,224.85
$m_{tank\text{-}OX\text{-}tot}$ (kg)	366,905.11
$m_{tank\text{-}press\text{-}tot}$ (kg)	567,478.23
$m_{press\text{-}tot}$ (kg)	449,496.60
$m_{LH\text{-}tot}$ (kg)	74,552.11
$m_{OX\text{-}tot}$ (kg)	447,312.64
$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00
SRM's	
$m_{booster\ tot\ inert}$ (kg)	174,120.00
$m_{booster\ tot\ wet}$ (kg)	1,171,682.00
$m_{SRM\text{-}prop\text{-}tot}$ (kg)	997,562.00
ΔV calculation	
$Isp_{stage\text{-}1}$ (s)	242.00
$m_{prop\text{-}tot}$ (kg)	997,562.00
$m_{inert\text{-}tot}$ (kg)	2,926,763.55
$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	675.3976769
F/W Calculation	
$m_{tot\text{-}initial}$ (kg)	4,028,825.55
$Thrust_{tot\text{-}SRM's}$ (N)	23,600,000.00
F/W	**0.597124008**

Stage 2a

SSME's	
$m_{prop\text{-}SSME\text{-}stg2a}$ (kg)	328,633.09
$m_{prop\text{-}LH\text{-}SSME\text{-}stg2a}$ (kg)	46,947.58
$m_{prop\text{-}OX\text{-}SSME\text{-}stg2a}$ (kg)	281,685.51
ET 2a&2b	
$m_{tank\text{-}LH}$ (kg)	839,224.85
$m_{tank\text{-}OX}$ (kg)	366,905.11
$m_{tank\text{-}press}$ (kg)	567,478.23
m_{press} (kg)	449,496.60
$m_{LH\text{-}tot}$ (kg)	74,552.11
$m_{OX\text{-}tot}$ (kg)	447,312.64
$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00
ΔV calculation	
$Isp_{stage\text{-}2}$ (s)	455.00
$m_{prop\text{-}tot}$ (kg)	328,633.09
$m_{inert\text{-}tot}$ (kg)	2,234,904.80
$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	586.7193334
F/W Calculation	
$m_{tot\text{-}initial}$ (kg)	2,668,037.89
$Thrust_{tot\text{-}SSME's}$ (N)	8,697,144.00
F/W	**0.332288767**

Stage 2b

SSME's	
$m_{prop\text{-}SSME\text{-}stg2b}$ (kg)	193,231.66
$m_{prop\text{-}LH\text{-}SSME\text{-}stg2b}$ (kg)	27,604.52
$m_{prop\text{-}OX\text{-}SSME\text{-}stg2b}$ (kg)	165,627.13
ET 2b	
$m_{tank\text{-}LH}$ (kg)	310,741.06
$m_{tank\text{-}OX}$ (kg)	135,854.52
$m_{tank\text{-}press}$ (kg)	210,121.03
m_{press} (kg)	166,435.79
$m_{LH\text{-}tot}$ (kg)	27,604.52
$m_{OX\text{-}tot}$ (kg)	165,627.13
$m_{inter\text{-}tank}$ (kg)	5,487.00
$m_{thermal\text{-}prot}$ (kg)	2,187.00
$m_{external\text{-}HW}$ (kg)	4,126.00
ΔV calculation	
$Isp_{stage\text{-}2}$ (s)	455.00
$m_{prop\text{-}tot}$ (kg)	193,231.66
$m_{inert\text{-}tot}$ (kg)	834,952.40
$m_{orb\ w/P/L}$ (kg)	104,500.00
ΔV (m/s)	834.8990544
ΔV_{tot} (m/s)	**2,097**
F/W Calculation	
$m_{tot\text{-}initial}$ (kg)	1,132,684.06
$Thrust_{tot\text{-}SSME's}$ (N)	6,522,858.00
F/W	**0.587029774**